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CONTENTS

Methyl bromide as a soil fumigant for controlling diseases and weeds in tobacco seedbeds - *R. H. Stover and L. W. Koch* 411

Blood serum protein content of mature range ewes as influenced by level of protein in their ration *F. Whiting, S. B. Slen and L. M. Bezeau* 421

Absorption and translocation of phosphorus by foliage - *W. F. Oliver* 427

Phloem necrosis of potato tubers associated with infestation of vines by *Paratrioza cockerelli* Sulc. - - - *G. B. Sanford* 433

A boron deficiency in pear growing in soil having an adequate boron content - *C. G. Woodbridge, A. Carney and H. R. McLarty* 440

The phenomenal decline of browning root rot (*Pythium* spp.) on the Canadian prairies - - - - - *T. C. Vanterpool* 443

Erratum - - - - - - - - - - - - - 453

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METHYL BROMIDE AS A SOIL FUMIGANT FOR CONTROLLING DISEASES AND WEEDS IN TOBACCO SEEDBEDS[1]

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Methods employed in the preparation of outdoor, cotton-covered seedbeds in the burley and dark tobacco belt of Ontario, and the cigar tobacco area of Quebec, are not always conducive to the production of disease-free tobacco seedlings. The muck soils or compost used in the preparation of these seedbeds as a rule are not steam-sterilized. As a consequence, the seedbed soil usually contains weed seeds, and often is infested with damping-off (*Rhizoctonia* and *Pythium* spp.) and black rootrot (*Thielaviopsis basicola*) organisms that develop freely and cause extensive injury when environmental conditions become favourable. On the other hand, practices followed in the extensive flue-cured areas of Ontario are much more likely to result in a satisfactory measure of control of soil-borne seedling diseases. In the latter areas, seedlings are grown in steam-sterilized soils under glass. Soil-steaming apparatus is not often available in the burley and cigar tobacco areas, and, when it is available for use, the growers usually do not consider steaming an economically feasible practice for the relatively small acreages involved. It appears, therefore, that a simple but safe economical treatment for the control of soil-borne seedling diseases would be of real assistance in the burley and cigar tobacco areas.

The use of chemicals to control weeds and diseases satisfactorily in tobacco seedbeds was perhaps first demonstrated with two synthetic nitrogen compounds, urea (uramon) and calcium cyanamide ("aero" cyanamid) (2). These two chemicals are recommended for use in seedbeds in some areas of the United States. They also have been tested in Ontario (4). However, their use is attendant with certain dangers, particularly in the organic (muck) soils used for seedling production in Ontario. Also, considerable labour is required in mixing the chemical with the soil, as well as in certain adjustments in subsequent fertilizer treatments. A method that may offer a safer and more satisfactory control under Ontario and Quebec conditions has been tested recently in the burley tobacco area. This treatment involves the use of methyl bromide gas.

Newhall and Lear (3) in New York State reported that methyl bromide (pure liquid) at the rate of 11 ml. per cubic foot gave satisfactory control of damping-off and of weeds in compost soil at 56° F.; also, that Dowfume

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G (10 per cent methyl bromide) at 50 ml. per cubic foot controlled damping-off. Control was most satisfactory when the soil was covered with a gas-proof tarpaulin. Methyl bromide was also reported to be effective in the control of weeds and seedling diseases in Kentucky, North Carolina, and South Carolina tobacco seedbeds (1). Wildfire was controlled by seedbed fumigation with methyl bromide in Kentucky.

The purpose of the present investigation was to determine the feasibility of using methyl bromide for the control of soil-borne tobacco seedbed diseases and weeds under conditions prevailing in certain parts of Ontario and Quebec.

EXPERIMENTAL PROCEDURE

A. Outdoor Treatments

In Ontario, cotton-covered seedbeds are made by placing a layer of screened muck soil about 4 inches deep on top of a layer of fresh horse manure or straw. The muck soil is usually replaced each year with fresh material from a pile brought to the seedbed in the fall from marsh areas. Material from such piles on tobacco farms was treated with methyl bromide in the fall when soil temperatures ranged from 60° to 65° F. Treatments were made about 2 days after a rain in order that sufficient moisture would be available to germinate weedseeds. For experimental purposes, the soil was placed in rectangular piles 1.5 feet deep, containing approximately 50 cubic feet (Plate I, Figure 2). Empty one-quart oil tins were used to support a covering of "visqueen" plastic (Figures 2 and 3). A trench from 4 to 5 inches deep was dug around the base of each pile. The edge of the plastic covering was placed in this trench and covered with soil, to form a seal (Figure 3). A length of plastic tubing was run under the covering and into a container where the end of the tube was anchored with a 1-inch piece of metal pipe. The proximal end of the tubing was attached to a Maclean applicator through which the liquid methyl bromide* in 1-lb. tins was released, the rate of application being 4 lb. per 100 cu. ft. of soil. This liquid then flowed into the pan under the plastic cover, where it vapourized. Then the tubing was removed and the opening sealed with soil. The plastic covering was removed after 48 hours.

Five piles of muck were treated on 4 farms in Kent County, designated 1A, 1B, 2, and 3 (Tables 1 and 2), during the first week of October. Four greenhouse flats of treated soil from each pile and two flats of the same soil untreated were obtained and seeded in the greenhouse with the Green Briar variety of burley tobacco (Table 1). A similar collection from all of the muck soils referred to was made in March (Table 2). The March collection was made to determine the amount of recontamination that occurred during the winter months in the exposed piles. Also, it was felt that the dormancy of many of the weed seeds might not have been broken in time for the October tests. The results of these experiments are given in Tables 1 and 2.

B. Greenhouse Treatments

Soil fumigation tests were also carried out in the greenhouse during the early spring. The soil consisted of a mixture of equal parts of a clay loam heavily infested with black rootrot, and a greenhouse compost. The

* The material used was Dowfume MC-2 containing 98 per cent methyl bromide and 2 per cent chloropicrin. A 1-lb. tin contains 262 ml.

Plate I

FIGURE 1. Apparatus used in fumigating infested and non-infested soils with different amounts of methyl bromide. The can holds 1 cu. ft. of soil. FIGURE 2. A pile of muck soil containing approximately 50 cu. ft. ready for covering and fumigation. The tins are used to support the plastic covering, and the tube delivering the fumigant is placed in the metal dish. FIGURE 3. The plastic covering is in place over the pile and fumigation is completed. Note how the edges of the covering are placed in a trench and covered with soil. FIGURE 4. Tobacco seedlings growing in black rootrot infested soil. The flat on the right was treated with 6 ml. per cubic foot of methyl bromide and the black rootrot fungus was eradicated. Note the prolific weed growth in the check flat (see Figure 5). FIGURE 5. The same two flats shown in Figure 4 with the seeds removed in the check to show the extensive areas of damping-off outlined by toothpicks, and stunting caused mainly by rootrot. The treated flat on the right was free from disease and weeds. FIGURE 6. Seedlings growing in muck soil from farm No. 2 (Table 1). The flat on the right was fumigated with methyl bromide and only a trace of damping-off is present (marked by toothpicks). Note the severe damping-off in the check.

TABLE 1.—THE EFFECT OF METHYL BROMIDE ON THE INCIDENCE OF DISEASE AND WEEDS IN FLATS OF TOBACCO SEEDLINGS GROWING IN DIFFERENT MUCK SOILS IN THE GREENHOUSE[1]

		Soil from tobacco farm		
		1A[2]	1B	2 (Figure 6)
Number of weeds per flat	Treated	4	1	0
	Check	40	16	70
Damping-off	Treated	Trace	Trace	Light
	Check	Severe	Light	Very severe

[1] Soils treated at the rate of 4 lb. per 100 cubic feet outdoors in October and tested in the fall.
[2] 1A, muck not previously used for tobacco seedlings; 1B, "used" muck.

TABLE 2.—THE EFFECT OF METHYL BROMIDE ON THE RELATIVE GROWTH AND FREEDOM FROM DISEASE OF TOBACCO SEEDLINGS IN DIFFERENT MUCK SOILS IN THE GREENHOUSE

		Soil from tobacco farm		
		1A (Figure 7)	2 (Figure 9)	3 (Figure 8)
Seedling height in inches	Treat[1]	2.30	2.70	2.10
	Check	0.50	1.25	0.70
Weight in grams[2]	Treat	10.10	11.00	6.60
	Check	1.75	3.25	2.50
Percentage damped-off	Treat	0	0	1
	Check	30	35	10
Number of weeds per flat	Treat	60[3]	0	7[3]
	Check	270	150	80

[1] Treated soils fumigated at the rate of 4 lb. per 100 cubic feet outdoors in October and tested in the spring.
[2] Average green weight of the tops of 25 seedlings chosen at random from each of 2 flats at 2 different times.
[3] Weeds were mallow (60) and clovers (7), which are resistant to the action of methyl bromide.

latter soil was known to be infested with damping-off fungi (*Rhizoctonia* and *Pythium* spp.). Cans containing 1 cubic foot of soil were used for these tests and the methyl bromide was applied by means of a 280 cc. graduated applicator* (Plate I, Figure 1). In each case the top of the can was covered with "visqueen" plastic the edges of which were sealed to the sides of the can with plastic tape. A tube from the applicator ran under the plastic and into a 6-inch length of 1-inch pipe that led to the centre of the soil. After applying the requisite dosage of the fumigant, the applicator valve was closed, the tube was withdrawn from the can, and the opening was sealed. Applications were made at the rates of 37, 15, 9.5, 6, 4.5, 3, and 2 ml. per cu. ft. of soil respectively. After 48 hours, three flats of soil from each treatment and 8 checks were seeded with Green Briar burley, a variety susceptible to black rootrot. Soil temperatures in the greenhouse varied between 61° and 65° F., and soil moisture was sufficient for weed seed germination. The results of these experiments are presented in Tables 3 to 6.

* Obtainable from Arrow Products Company, 447 Lincoln Street, Carlstadt, New Jersey.

TABLE 3.—THE EFFECT OF METHYL BROMIDE ON THE INCIDENCE OF SEEDLING DISEASE AND WEEDS IN BLACK ROOTROT INFESTED SOIL IN THE GREENHOUSE

Methyl bromide per cu. ft. (ml.)	Incidence of disease	Number of weeds per flat
37	None	25[1]
15	None[2]	8
9.5	None	1
6.0	None[2]	2
Check	Severe damping-off and black rootrot	100

[1] All weeds in the treated flats were clover spp. (see Table 7 for other types); a prolific growth of *Pyronema* sp. occurred on the surface of the soil treated at the 37 ml. rate. In contrast to prolific growth on steam-sterilized soils, *Pyronema* sp. was not observed at the lower concentrations of MBr_2 used.

[2] Damping-off (*Rhizoctonia* sp.) was present in one flat and was caused by contamination.

TABLE 4.—THE EFFECT OF METHYL BROMIDE ON THE RELATIVE GROWTH AND FREEDOM FROM DISEASE OF TOBACCO SEEDLINGS GROWING IN BLACK ROOTROT INFESTED SOIL IN THE GREENHOUSE

Methyl bromide per cu. ft.	Weight[1]	Height	Incidence of disease	Number of weeds per flat
ml.	gm.	in.		
6	17.5	2.5	None	5
4.5	14.5	2.8	None	4
Check	8.3	1.3	Severe[2]	154
3	24.8	2.8	None	8
2	14.5	2.0	Moderate[3]	12
Check	8.2	1.3	Severe[3]	192

[1] Average green weight of tops of 25 seedlings chosen at random from each of 3 flats.

[2] Thirty per cent of flat area damped-off; 85 per cent of seedlings infected with black rootrot, 25 per cent severely infected.

[3] See Table 5.

TABLE 5.—THE EFFECT OF CRITICAL CONCENTRATIONS OF METHYL BROMIDE ON THE INCIDENCE OF BLACK ROOTROT AND DAMPING-OFF OF TOBACCO SEEDLINGS IN BLACK ROOTROT INFESTED SOIL

Methyl bromide per cu. ft.	Damping-off		Incidence of black rootrot[1]				
	Rhizoctonia sp. *Pythium* sp.	*T. basicola*	None	Trace	Light	Moderate	Severe
	Seedlings killed	Number of seedlings killed					
ml.	%		%	%	%	%	%
3	0	0	100	0	0	0	0
2	0	20	33	43	16	5	3
Check	30	60	0	38	14	23	25

[1] Roots examined 8 weeks after seeding.

TABLE 6.—THE EFFECT OF METHYL BROMIDE ON WEED GERMINATION IN BLACK ROOTROT INFESTED SOIL

Dosage of methyl bromide (ml. per cu. ft.)	Weeds	
	Average number per flat	Species present[1]
37.0	25.0	Clover spp. only
15.0	18.0	Clover spp. only
9.5	1.0	Clover spp. only
6.0	2.0	Clover spp. only
5.0	3.0	Clover spp. only
4.5	2.0	Clover spp. only
3.0	8.0	Clover spp. only
2.0	9.0	Clover spp. only
Average number of weeds per flat—all treatments	8.5	—
Average number of weeds per flat—non-treated	167.0	—

[1] In marked contrast to the absence in treated flats of all weeds, except clover in small amount, all check flats supported large weed populations. The species present and the average number in each untreated flat were as follows: clover spp. (50), grass spp. (44), lamb's quarters (14), pigweed (12), purslane (12), ragweed (7), catnip (6), plantain (3), nightshade (1), unidentified (5).

EXPERIMENTAL RESULTS

A. Outdoor Treatments

In Table 1, the results of the fall greenhouse tests as described above are given. In this preliminary experiment, it is evident that excellent control of damping-off organisms present in the fumigated soil was obtained as contrasted with the same soils non-fumigated (Plate I, Figure 6). Weed control was good, although most of the late summer and fall crop of weed seeds were still dormant, as is indicated by the large increase in the number of weeds in the same soils in March (Table 2). Even where disease in the form of damping-off was not a factor, a slight but pronounced stimulation of seedling growth was noted in the fumigated soils. This increase in the relative growth of seedlings in the fumigated soils was measured in the next series of experiments.

In Table 2, the results of greenhouse tests in the spring on the commercial muck piles treated during the previous fall are given. These soils, which include two of the same dealt with in Table 1, had been exposed outdoors in the treated piles during the winter months. Three facts were clearly illustrated in this experiment. First, as an examination of Table 2 reveals, control of damping-off organisms in the treated soil was excellent. Second, weed control was good with the exception of mallow (*Malva rotundifolia*) and clover spp. In soil 1A, a heavy infestation of mallow seeds was present and these were apparently completely unaffected by the fumigant. When the mallow was removed from all flats early in the course of the experiment, no other weeds appeared in the treated soil. In contrast, about 10 different species of weeds appeared in the checks (Plate II, Figure 8). Third, a pronounced and significant stimulation of seedling growth occurred in all fumigated soils as contrasted with growth in non-fumigated soils (Plate II, Figures 7-9). This stimulation was evident even when damping-off was not present in the checks and weeds were not a competing

factor (Plate II, Figure 8). On the other hand, in flats in which a heavy population of weeds was allowed to develop, the tobacco seedlings were less vigorous than in weed-free, fumigated soils.

In so far as the tobacco seedbeds prepared from the treated outdoor commercial muck piles on different tobacco farms are concerned, in all cases but one they proved to be satisfactory. Although circumstances prevented a careful evaluation of the different treatments in these seedbeds, it may be stated that, in general, the results of disease and weed control in all outdoor seedbeds, except in the one instance referred to, confirmed the results obtained in the greenhouse, which are summarized in Tables 1 and 2.

In the one exception mentioned above, there was severe stunting of Harrow Velvet seedlings in the treated portion of muck soil. Roots of affected seedlings were discoloured even to the meristematic regions of the root tips, but an examination of them did not disclose the presence of any pathogenic fungi or other organisms. Furthermore, not only did tobacco seedlings manifest these symptoms in the treated soil in question, but also a single plant of lamb's quarters, from seed which either survived the treatment or re-contaminated the soil, showed similar symptoms. However, when soil from the treated portion of the seedbed where stunting developed was brought into the greenhouse and re-seeded, in all cases, regardless of the temperature at which they were maintained, the seedlings developed normally. It should be mentioned that a 4-8-6 commercial fertilizer mixture at the rate of 1 bag per 900 sq. ft. had been applied at the time of seeding to the outdoor seedbed in which the stunting occurred; also, that the outdoor temperatures and consequently those of the seedbeds were unusually low for a period of 10 days after seeding. In a consideration of the various factors, including available soil nutrients, which might have been responsible for the stunting of the tobacco seedlings in the one instance where it occurred, it was decided that it was somehow associated with the heavy application of fertilizer to the outdoor seedbed and perhaps also with the unusually low temperatures which prevailed for a period of approximately 10 days afterwards. This conclusion would appear justified in view of the fact that, when soil from the treated portion of the seedbed where trouble developed was brought into the greenhouse both before application of the fertilizer and afterwards, and then re-seeded, invariably growth of the tobacco seedlings was normal. Further confirmation of this conclusion and probably also the cause of the toxicity was strongly indicated by chemical soil analyses of the seedbed where the trouble occurred. Soluble salts proved to be at an exceptionally high level in the treated portion and considerably lower in the non-treated portion. Both nitrite-nitrogen and potassium were well above the danger level in the treated soil. Thus, it may be concluded that stunting of the tobacco seedlings in the seedbed in question arose because of soluble salts injury due to the excessive application of fertilizer. Low temperatures accompanied by high moisture immediately after seeding probably aggravated the condition. That the toxic condition was of a transitory nature was further indicated, as mentioned previously, by the fact that re-seeding of the soil soon after the seedling failure was observed resulted in normal growth.

Plate II

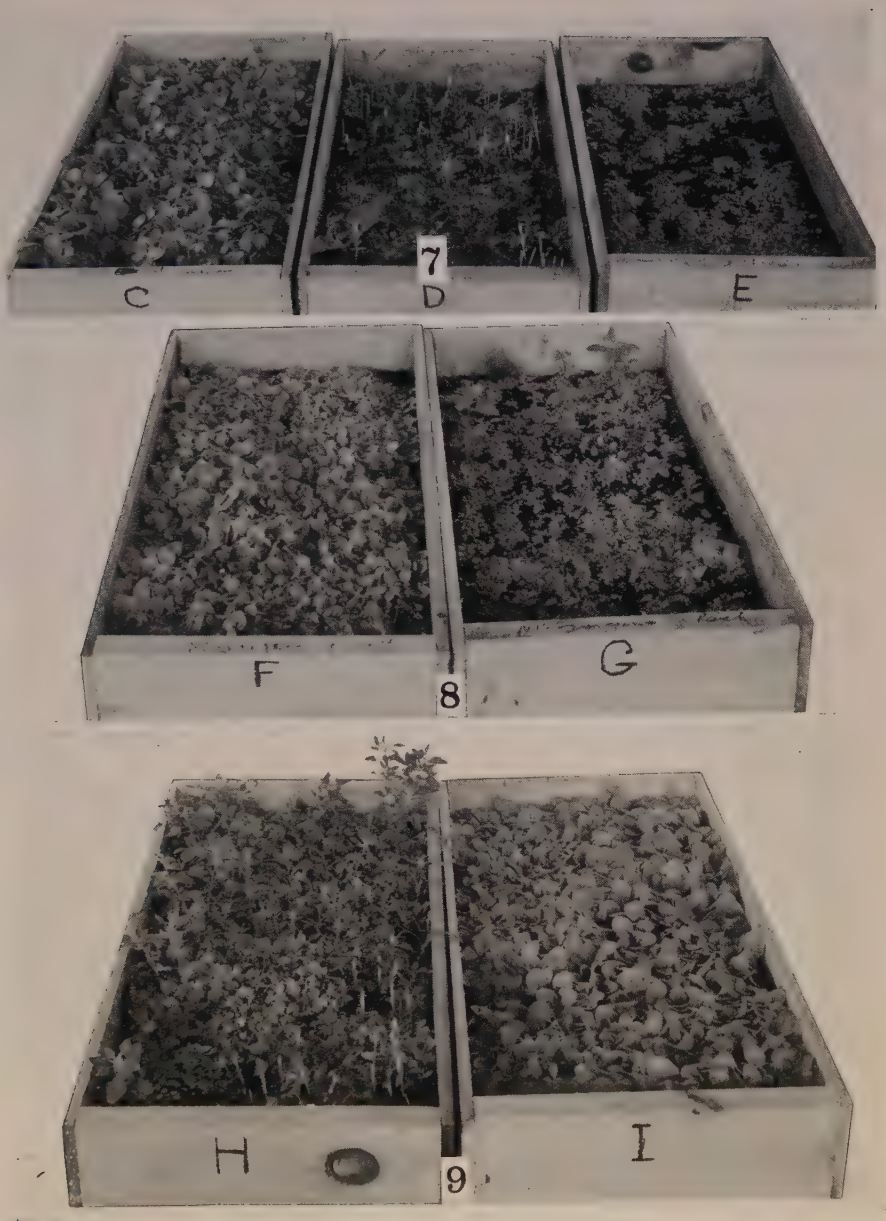
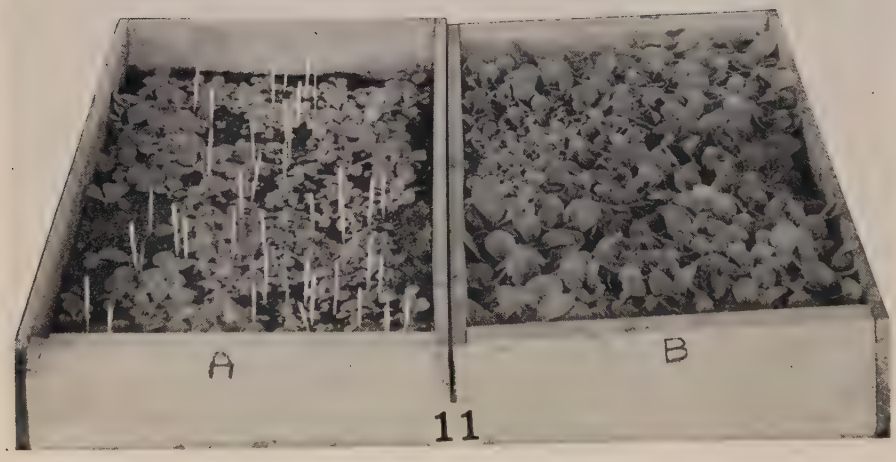


FIGURE 7. Seedlings growing in muck soil from farm No. 1A (Table 2); C was fumigated with methyl bromide; D, non-fumigated (a check in which the weeds were allowed to develop); E, non-fumigated (a check in which the weeds were not allowed to develop). Note the better growth in C and the areas of damping-off in D. Damping-off and weeds are not a factor in the poorer growth of the seedlings in E when contrasted with their growth in C. FIGURE 8. Seedlings growing in muck soil from farm No. 3 (Table 2). Note the increased growth in the fumigated flat F contrasted with the non-fumigated flat G. Damping-off was not a factor in the reduced growth in G. FIGURE 9. Seedlings growing in muck soil from farm No. 2 (Table 2). Note the infestation of weeds and damping-off in the check flat H contrasted with the fumigated flat I. Figures 7, 8, 9 photographed 6 weeks after seeding.

Plate III

10



11

FIGURE 10. *Left to right*—Seedlings of the varieties Little Crittenden, Kelley, and Harrow Velvet growing in field soil heavily infested with black rootrot. The three flats in the background were fumigated with methyl bromide. Note the increased growth in fumigated soil of Harrow Velvet, a variety highly resistant to black rootrot. Seedlings photographed 4 weeks after planting (see Table 8). FIGURE 11. Seedlings of the black rootrot susceptible variety Green Briar growing in rootrot infested soil. Flat B was fumigated with 4.5 ml. of methyl bromide per cu. ft. Both damping-off and black rootrot contributed to the poor growth and stand in the check flat A.

B. Greenhouse Treatments

The soil in these experiments was heavily-infested with both black rootrot and damping-off organisms. The effect of different concentrations of methyl bromide on diseases caused by these fungi is shown in Tables 3 to 5.

In Table 3, the results of a preliminary experiment are shown. In an examination of the roots of seedlings grown in soils treated with as little as 6 ml. of methyl bromide per cubic foot (approx. $2\frac{1}{4}$ lb. per 100 cubic feet), no evidence of black rootrot was found. In contrast, rootrot and damping-off were severe in all check flats (Plate I, Figures 4, 5). Damping-off appeared in one flat in each of the 15 and the 6 ml. per cubic foot series. This disease did not appear until about 5 weeks after the experiment was begun, and its presence is attributed to contamination. It is not infrequently observed, even in steam sterilized soils, that contamination of a dense growth of young succulent seedlings with *Rhizoctonia* sp. occurs and the organism spreads rapidly across the surface of the flat under warm, humid conditions. This may occur on any flat if conditions are satisfactory, regardless of the method of soil treatment.

Table 4 shows the effect of lower concentrations of methyl bromide on the growth of seedlings and incidence of disease (Plate III, Figure 11). It will be observed that the critical concentration of methyl bromide for the control of black rootrot under the conditions of this experiment is between 2 and 3 ml. per cu. ft. of soil.

Examination of Table 5 shows that damping-off due to *Rhizoctonia* and *Pythium* species was absent even at the 2 ml. per cu. ft. level. A measure of control of black rootrot was also obtained at this rate. At 3 ml. per cu. ft., the black rootrot fungus was completely eradicated. It will also be noted that damping-off caused by *Rhizoctonia* and *Pythium* spp., as well as black rootrot, were severe in the checks.

The effect of the various concentrations of the chemical on weeds in the above experiments is shown in Table 6. Clover was the only weed present in the treated flats at all concentrations of methyl bromide used. It is evident, however, by comparing the checks and the treated flats that a large proportion of the seeds of this species is destroyed by the treatment. The greater survival of these seeds at the two highest levels of fumigant used is not readily explainable.

As in the outdoor treatments, it was observed that a certain stimulation of seedling growth occurred in the fumigated soils. That this stimulation was not due entirely to the elimination of pathogenic organisms was also evident. In the check flats, approximately 38 per cent of the seedlings showed only a trace of disease (Table 5), consisting in many cases of 1 or 2 small black rootrot lesions near the end of feeder roots. The remaining roots appeared white and healthy. These lesions alone were not sufficient to cause the retarded growth when contrasted with seedling growth in treated flats. To determine how much of the stimulation was due to the elimination of pathogenic fungi, a soil* heavily infested with black rootrot was treated with 10 ml. of methyl bromide per cu. ft. This treated soil and corresponding checks were planted with seedlings of Little Crittenden and

* This soil was a clay loam from black rootrot plots that had grown tobacco for 9 consecutive years.

TABLE 7.—THE RESPONSE OF RESISTANT AND SUSCEPTIBLE TOBACCO VARIETIES GROWING IN FUMIGATED[1] AND NON-FUMIGATED BLACK ROOTROT-INFESTED SOIL

Variety	Black rootrot rating		Green weight in gram (6 plants)	
	Fumigated	Check	Fumigated	Check
Kelley	0	65	50.0	10.0
Little Crittenden	0	70	45.0	5.0
Harrow Velvet	0	20[2]	50.5	8.5

[1] Ten ml. methyl bromide per cu. ft. of soil; seedlings harvested 4 weeks after planting.
[2] A trace only of black rootrot but growth and root system unsatisfactory.

Kelley, two varieties highly susceptible to black rootrot, and Harrow Velvet a highly resistant variety. The results of this experiment are tabulated in Table 7 (*cf.* Plate III, Figure 10).

It will be observed in Table 7 that all three varieties grow better in the fumigated soil irrespective of their resistance or susceptibility to black rootrot. Although there was only a trace of black rootrot on Harrow Velvet, this resistant variety grew no better than the severely affected susceptible varieties for the first 4 weeks of the experiment. Several weeks later, however, it outgrew the susceptible varieties, thus confirming previous similar observations by Stover (5) following fumigation of this same soil. Although the root system of Harrow Velvet was white and appeared healthy, completely lacking the brown lesions consistently associated with brown rootrot caused by nematodes, yet it could only be described as unthrifty. It is believed, therefore, that this unthriftiness cannot be explained by nematode injury alone. It is probable that some complex biological factor related to both soil flora and fauna is involved. Also, the effect of fumigation on the various chemical constituents of the soil must be considered.

DISCUSSION

In greenhouse experiments concerning tobacco seedling production, fumigation of the seedbed benefited the plants, not only through the destruction of specific soil-borne pathogens and weedseeds, but also through a growth-stimulating effect similar to that observed in steam-sterilized soils. This stimulating effect has been shown to be independent of the presence of common soil-borne pests. Although no direct comparison has been made between steamed and fumigated soils, it would appear that fumigation with methyl bromide is comparable to steaming, the beneficial effects of which are attributed to growth stimulation and the destruction of pests. A comparison between the cost of steaming and of fumigating indicates that the latter is considerably cheaper. At the rate of 2 lb. of methyl bromide per 100 cubic feet of soil the prevailing cost of fumigating seedbed soil is approximately one-half that of steaming.

The results of these experiments have shown that the 2-lb. rate is sufficient to destroy all soil-borne pathogens under Ontario conditions. In fact the elimination of damping-off fungi and weeds was obtained at dosages as low as 2 ml. per cubic foot of soil (less than 1 lb. per 100 cu. ft.). However, the black rootrot fungus was not completely eradicated at this dosage, although a fair measure of control was obtained.

Fumigation of seedbed soils is particularly applicable in the burley, dark, and cigar tobacco districts. In these areas the seedbed soils (muck and compost) are placed in piles near the seedbed thus presenting for treatment a single compact soil area. Although it is necessary to treat the soil in the fall when soil temperatures are above 60° F., this can usually be successfully accomplished as late as the middle of October, when the busy harvesting period is past.

While the present experiments in connection with the use of methyl bromide in outdoor seedbeds have shown that it is not impossible under certain conditions to create a temporary soil toxicity and thus injure seedlings as, for example, in a muck soil where the level of available mineral nutrients may be dangerously high beforehand, nevertheless, under average conditions this chemical should prove to be highly useful in the field of seedling production.

It is common practice for farmers to renew their seedbed soils each year at a cost of from $25.00 to $100.00, depending on the size of the seedbed. This practice has been adopted mainly to prevent carry-over or build-up of disease organisms. As methyl bromide destroys all the common soil-borne disease organisms encountered under Ontario and Quebec conditions, this replacement would no longer be necessary from the disease standpoint. If the muck soil supports a good growth of seedlings, and is of high fertility, there is no reason why it could not be used for several years, provided it is treated to kill disease-producing organisms. The effect of methyl bromide on the oospores of blue mould (*Peronospora tabacina*) is not known. However, there is no reason to believe that the oospores of this fungus are any more resistant to chemical action than are the oospores of *Pythium* species or the heavy-walled chlamydospores of *Thielaviopsis basicola*. Incidentally, in the present studies tobacco mosaic virus survived in pieces of infected leaf petiole buried in soil treated at the 4 ml. per cu. ft. rate. Therefore, if a seedbed is infected with this virus, precautions should be taken to remove the seedlings before using the soil again.

SUMMARY

1. The efficacy of methyl bromide as a soil fumigant for controlling diseases and weeds in tobacco seedbeds was tested both in the greenhouse and outdoors with a view to its applicability for use in burley and dark type tobacco growing areas of Ontario and cigar and pipe tobacco areas of Quebec.

2. These experiments showed that methyl bromide at 2 lb. per 100 cu. ft. was sufficient to destroy all soil-borne tobacco pathogens under Ontario conditions. Elimination of damping-off fungi and weeds (except clover) was obtained at dosages as low as 2 ml. per cu. ft. of soil (less than 1 lb. per 100 cu. ft.). The black rootrot fungus was partially eradicated at the latter dosage, and entirely so at the 2-lb. level.

3. Tobacco seedlings, with few exceptions, appeared to benefit from soil fumigation with methyl bromide, not only through the destruction of specific soil-borne pathogens and weed seeds, but also through a growth-stimulating effect. The latter was shown to be independent of the presence of common soil-borne pests.

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BLOOD SERUM PROTEIN CONTENT OF MATURE RANGE EWES AS INFLUENCED BY LEVEL OF PROTEIN IN THEIR RATION[1]

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Very few studies have been conducted to determine the influence of various nutrients in the ration of mature sheep upon the protein content of their blood. Such information would be of value, if the ration does influence the blood protein content, in evaluating the nutritional status of the ewe.

Klosterman *et al.* (6) reported that pregnant ewes fed rations of low protein content had a lower blood serum albumin content than those fed a liberal or adequate amount of protein. Serum globulin was not affected by the rations fed. In their first experiments total blood serum protein was reduced by feeding a low-protein ration but was not influenced by similar rations in their second experiment.

Howe (5) reported that feed had little effect upon the albumin or globulin content of sheep serum.

Dalgarno *et al.* (2, 3) reported that the total blood serum protein content of ewes on a high plane of nutrition during the latter stages of pregnancy was higher than that of similar ewes on a low plane of nutrition. However, there was no significant difference between the albumin : total protein ratio of the serum from the low- and high-plane fed ewes. The serum albumin tended to rise and the globulin tended to fall at the end of pregnancy.

In the course of studies previously reported (7, 8) designed to study the influence of the level of protein in the ration of mature ewes upon wool and lamb production, an opportunity was afforded to study the level of total blood serum protein, serum albumin, and serum globulin as influenced by level of protein in the ration and as influenced by pregnancy and lactation. The data obtained in this study and in the study carried out during 1950–51 (9) are presented in this paper.

PROCEDURE

1949–50 Experiment

Three groups of 27 mature (3- and 4-year-old) range ewes of Corriedale breeding weighing approximately 125 pounds were fed rations containing 7.5, 10.4, and 12.6 per cent total protein from June, 1949 until June, 1950. The rations contained 70 per cent grass hay and 30 per cent concentrate (molasses, starch, oats, linseed oilmeal, and minerals) and were fed in pelleted form. These ewes were nursing single lambs when placed on experiment in June, 1949. The lambs were weaned in September and the ewes were bred to lamb during the following April. All ewes were fed in individual stalls twice daily. Details regarding the composition of the rations fed and management of the sheep were described in a previous paper (7).

[1] Contribution from the Division of Animal Husbandry, Experimental Farm Service, Canada Department of Agriculture, Ottawa.

Seven ewes selected at random from each group were bled by jugular venipuncture in June, 1949, (before the ewes were placed upon their experimental rations), again on August 9 (just before the lambs were weaned), on October 3 (when the ewes were dry and before the breeding season), on February 7 (approximately 2 months before lambing), and on May 3 and June 2 (approximately 1 and 2 months, respectively, after lambing). The random selection was made with the restriction that if a ewe was selected that had not consumed her daily allowance of feed during the previous 2 weeks she was not bled and another ewe was selected at random in her place. For the May 3 and June 2 bleeding a further restriction was imposed in that only ewes that had lambed during the first 2 weeks in April, and that were nursing single lambs, were bled.

Total blood serum protein (N $\times$ 6.25) was determined by the Macro-Kjeldahl method using copper sulphate and potassium sulphate as catalysts. Albumin was determined using the colorimetric method of Stiff (10) which employs 23 per cent sodium sulphate to separate albumin from globulin, and non-protein nitrogen was determined on a few samples using the method outlined by Hawk, Oser, and Summerson (4). Globulin was determined by differences, that is, total protein less albumin.

1950–51 Experiment

Three groups of 20 mature range ewes similar to the ones used the previous year were fed from June, 1950 to September, 1951 rations containing approximately the following amounts of protein: Lot 1, 7.7 per cent; Lot 2, 7.7 per cent protein until 6 weeks before lambing (February 14) and then raised to 10.5 per cent; and Lot 3, 10.5 per cent protein. The rations fed, method of feeding etc., were similar to those used during the first experiment.

Seven ewes from each lot, selected as in the first experiment, were bled on September 7 (a few days before the lambs were weaned), on November 7 (before breeding), on February 7 (about 7 weeks before lambing), and on May 16 (6 weeks after lambing). Methods of blood analysis were similar to those used during the first experiment.

RESULTS AND DISCUSSION

The data on total serum protein, serum albumin and globulin, and non-protein nitrogen obtained from the 1949–50 experiment are presented in Table 1. Similar data obtained from the 1950–51 experiment are presented in Table 2.

Total Serum Protein

From the data presented in Table 1 it is evident that there were no significant differences in total serum protein content between lots until May 3 when the ewes were at the peak of lactation, with the exception that when bled on October 3, Lot 3 showed a significantly ($P < 0.01$) higher serum protein content than the other 2 lots. No explanation can be offered as to why the ewes in Lot 3 bled on that date should be higher than the other ewes. The ewes in all groups showed a slow rise in total serum protein content from the beginning of the experiment (mid-lactation) until

TABLE 1.—BLOOD SERUM PROTEIN CONTENT OF THE MATURE EWE AS INFLUENCED BY THE LEVEL OF PROTEIN IN THE RATION AND BY PREGNANCY AND LACTATION, 1949–50 EXPERIMENT

		Lot 1	Lot 2	Lot 3
No. of ewes bled		7	7	7
Av. protein content of ration[1]	(%)	7.5	10.4	12.6
Av. daily dig. crude protein intake	(lb.)	0.13	0.24	0.30
Av. daily total dig. nutrient intake	(lb.)	1.9	2.1	2.1
Total Serum Protein (gm./100 ml.)				
June 20, start of expt., mid-lactation)		6.0	6.1	6.3
Aug. 9 (end of lactation)		6.3	6.5	6.5
Oct. 3 (dry)		6.3	6.4	7.0
Feb. 7 (7 weeks before lambing)		6.6	6.7	6.8
May 3 (1 month after lambing)		5.7	6.3	6.4
June 2 (2 months after lambing)		5.3	6.3	6.7
Serum Albumin (gm./100 ml)				
June 20		—	—	—
August 9		3.8	3.8	3.7
October 3		3.7	3.8	4.5
February 7		4.5	4.6	4.9
May 3		3.6	4.3	4.4
June 2		3.4	4.0	4.2
Serum Globulin[2] *(gm./100 ml.)*				
June 20		—	—	—
August 9		2.5	2.7	2.8
October 3		2.6	2.6	2.5
February 7		2.1	2.1	1.9
May 3		2.1	2.0	2.0
June 2		1.9	2.3	2.5
Serum Non-Protein Nitrogen (Mg./100 ml.)				
May 3		17	28	33
June 2		14	28	30

Minimum significant difference between lot means at one date or between date means within one lot ($P = 0.01$)

Total protein	0.5 gm.
Albumin	0.4 gm.
Globulin	0.4 gm.

[1] Dry matter basis.
[2] Determined by difference.

mid-pregnancy. At the end of the first month of lactation all lots had significantly lower serum protein content than at mid-pregnancy. There was a further fall in serum protein level in Lot 1 from the first to second month of lactation. However, there was no change in Lot 2 during the first to second month of lactation and a slight rise in Lot 3. The ewes in Lot 1 had a significantly lower serum protein content during lactation ($P < 0.01$) than the other 2 lots. There were no differences between Lots 2 and 3 at the end of one month of lactation but a significant difference ($P < 0.05$) at the end of the second month of lactation.

The data obtained during 1950–51 confirm the 1949–50 data with the exception that the ewes in Lots 1 and 2 had significantly lower serum protein content than Lot 3 approximately 7 weeks before lactation.

TABLE 2.—BLOOD SERUM PROTEIN CONTENT OF THE MATURE EWE AS INFLUENCED BY THE LEVEL OF PROTEIN IN THE RATION AND BY PREGNANCY AND LACTATION, 1950–51 EXPERIMENT

		Lot 1	Lot 2	Lot 3
No. ewes bled		7	7	7
Av. protein content of ration[1]	(%)	7.7	7.7→10.5	10.5
Av. daily dig. crude protein intake	(lb.)	0.12	0.12→0.21	0.21
Av. daily total dig. nutrient intake	(lb.)	2.0	2.1	2.1
Total Serum Protein (gm./100 ml.)				
September 7 (before weaning)		6.0	6.0	6.4
November 7 (dry)		6.5	6.5	6.6
February 7 (7 wk. before lambing)		6.1	6.1	6.7
May 16 (6 wk. after lambing)		5.2	5.7	6.4
Serum Albumin (gm./100 ml.)				
September 7		3.9	3.9	4.1
November 7		4.3	4.3	4.4
February 7		4.1	4.1	4.2
May 16		3.1	3.5	4.1
Serum Globulin[2] *(gm./100 ml.)*				
September 7		2.1	2.1	2.3
November 7		2.2	2.2	2.2
February 7		2.0	2.0	2.5
May 16		2.1	2.2	2.3
Non-Protein Nitrogen (mg./100 ml.)				
November 7		26.1	26.1	34.3

Minimum significant difference between lot means at one date or between date means within one lot (P = 0.01)

Total protein	0.5
Albumin	0.4
Globulin	0.4

[1] Dry matter basis.
[2] Determined by difference.

Increasing the protein content of the ration fed to Lot 2 six weeks before lambing resulted in the ewes in this lot having a serum protein content significantly higher during lactation than the ewes that remained on the low level, but not as high as those in Lot 3 that were on the higher level of protein throughout pregnancy and lactation.

These data indicate that the serum protein content was not affected significantly by the rations fed until the additional stress of lactation was imposed upon the ewe. That is, the low-protein ration apparently supplied sufficient protein to maintain a normal blood serum protein content until the additional protein requirements for lactation were imposed. This would indicate that a normal serum protein content is maintained at the expense of other physiological processes when protein is supplied in inadequate amounts, in that the growth of wool on the ewes receiving the low-protein ration was significantly less than on the ewes receiving higher protein rations (7) during the period prior to lactation. Because other body functions are impaired before the protein content of the serum is changed, blood serum protein content is not a sensitive index of the protein requirement of the ewe. However, serum protein content could be used as an index to detect quite marked protein deficiency.

The data also indicate that there is a storage of reserve protein in the body of the ewe in that increasing the protein content of the ration from 7.7 to 10.5 per cent 6 weeks before lambing did not result in as high total serum protein content in the ewes in Lot 2 during lactation as in the ewes in Lot 3 that were on a 10.5 per cent protein ration throughout pregnancy and lactation. Whipple (11) and others have shown that there are dispensable stores of protein in the animal body that are used when the protein needs of the body exceed the protein intake.

The total serum protein levels reported in this paper are slightly lower than the values reported by Klosterman *et al.* (6) for pregnant ewes and by Becker and Smith (1) for mature ewes but are higher than those reported by Dalgarno *et al.* (3) for ewes 10 days before parturition and by Howe (5) for sheep (age not given).

Serum Albumin Content

The trend in serum albumin content followed very closely that found for total serum protein. In fact, most of the changes in total serum protein content could be accounted for by changes in the albumin content. Klosterman *et al.* (6) reported similar findings. In the 1949–50 experiment the serum albumin content was highest at mid-pregnancy. During lactation, albumin was significantly lower than during pregnancy.

There were no significant differences between lots until during lactation. In both years the low-protein group had a significantly lower ($P < 0.01$) serum albumin content during lactation than the other lots. There was no significant difference in albumin content between the group receiving 10 and 13 per cent total protein in their ration. In 1950–51, the ewes whose ration was increased from 7.7 per cent protein to 10.5 per cent protein approximately 7 weeks before lambing had a significantly higher albumin content than the ewes that remained on the 7.7 per cent protein ration, but they did not have as high albumin content as those that received the higher protein ration during pregnancy and lactation.

The serum albumin content reported in this paper are higher than those reported by Klosterman *et al.* (6) who used 42.5 per cent methanol for the separation of albumin and globulins, but are slightly lower than those reported by Dalgarno *et al.* (3) who used saturated magnesium sulphate for the separation of albumin and globulin.

Serum Globulin

There were no significant differences in the serum globulin content between rations with the exception of the June 2, 1950 bleeding, at which time Lot 1 ewes had significantly lower globulin content than Lots 2 and 3. During the 1949–50 experiment all ewes had lower serum globulin content during pregnancy and early lactation than at other times, but during the 1950–51 experiment there were no significant differences either between lots or between dates. Klosterman *et al.* (6) found no differences in globulin content of ewes receiving various amounts of protein in their rations.

Non-Protein Nitrogen

Since non-protein nitrogen was determined only at infrequent intervals no definite conclusions can be drawn. However, the data indicate that ewes receiving low-protein rations have a lower serum non-protein nitrogen content than ewes receiving higher protein allowances.

SUMMARY

Seven mature ewes selected at random from each of 3 groups receiving rations containing 7.5, 10.4, and 12.6 per cent total protein were bled at various intervals during 1949–50 and their blood serum analysed for total protein (N × 6.25), albumin, globulin (by difference), and N.P.N. content. During 1950–51, 7 ewes from each of 3 groups receiving rations containing 7.7 per cent, 7.7 per cent raised to 10.5 per cent 6 weeks before lambing, and 10.5 per cent protein were bled also at various intervals and their blood analysed for the same constituents as in 1949–50.

There were no significant differences in total serum protein or albumin content between groups until late pregnancy and during lactation. During lactation the group receiving the low-protein ration had significantly lower ($P < 0.01$) total protein and albumin content in their serum than those receiving higher protein intakes. All groups had lower serum protein and albumin content during lactation than during the dry period and during pregnancy.

Serum globulins were not influenced to any marked extent by rations fed or by pregnancy and lactation. Non-protein nitrogen content of the serum was higher in ewes receiving the higher protein rations.

The total serum protein content and/or serum albumin content were not sensitive indices of the protein requirements of the mature ewe.

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ABSORPTION AND TRANSLOCATION OF PHOSPHORUS BY FOLIAGE[1]

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INTRODUCTION

Stanford *et al.* (3) have compared the uptake of phosphorus from surface applications of fertilizer with the uptake from fertilizer applied with the seed. In these studies the phosphorus content of the foliage was higher where the phosphate was applied as surface dressing, the actual phosphorus content being appreciably higher than might have been expected. Similar experiments with radioactive phosphorus on permanent pastures at Macdonald College have exhibited surprisingly high phosphorus uptake (1). It seemed possible that this might be explicable in part by absorption of phosphorus from phosphatic fertilizer which found its way on to the surface of the foliage either at the time of application or by being splashed on to the foliage from the soil surface by raindrops. Accordingly, a series of qualitative experiments was planned to ascertain, by the use of labelled phosphatic fertilizer, the extent to which phosphorus thus applied to the foliage is absorbed and translocated to other parts of the plant. The experiments included tests in which the fertilizer was either spotted or splashed on to the leaves of corn and bean plants.

Wittwer and Lundall (4) have published recently the results of somewhat similar studies of foliar absorption. However, the technique described in the present paper would appear to demonstrate the effect in a somewhat more striking fashion.

MATERIALS AND METHODS

Experimental Plants

Corn and bean plants were grown in small flats in the open. When the plants were one month old, they were treated with labelled phosphate. Counts of radioactivity were conducted on the plants at intervals during the succeeding three weeks. During the latter period the plants were maintained indoors at 68° F. and 50 per cent relative humidity in a constant temperature and humidity room. The plants were illuminated by a bank of fluorescent lamps which were switched on for 12 hours each day.

Application of Labelled Phosphate

(*a*) *By splashing.*—Commercial superphosphate passing the 10-mesh but refusing the 40-mesh sieve was irradiated with neutrons to a specific activity of 0.1 mc./gm. This irradiated material was held for 11 days before use in these experiments, an interval believed adequate to obviate any significant interference from induced radioactivity in possible impurities.

[1] Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Journal Series No. 298.

[2] Chairman, Macdonald College Tracer Committee.

The measured half-life was 14.3 days. Radioactive superphosphate (specific activity 0.06 mc./gm.) was then scattered on the surface of a strip of soil about four inches in width and situated at the edge of a flat containing soil only. The rate of application was 400 lb. superphosphate per acre. For reasons of safety the fertilizer was applied 10 minutes before a heavy rainstorm (rainfall: 1.0 inches in 5 hours). It was possible to time the application in this way because of information provided from the Radar Division of the Meteorological office at the Montreal Airport.

A flat containing a row of beans was placed beside the flat containing the active fertilizer. Two plastic shields, mounted on wooden frames, were then set up quickly so as to expose about one-quarter of the foliage to splashes from the fertilizer flat. The rest of the foliage was not shielded from rain or splash from the inactive side. Immediately after the rain the foliage was monitored. It was found that the protected portions of the foliage and also the soil in which the plants were growing had both been adequately shielded from splash from the active side.

The experiments on corn were set up in a similar way.

(*b*) *By spotting.*—One gram of neutron irradiated superphosphate (activity 0.06 mc.) was placed on filter paper on a funnel. The soluble fraction was removed by leaching with 250 ml. distilled water (2). The plants were divided into groups and "spot" applications made with the active solution on leaves and stems (one spot per plant) of corn and beans as follows:

(i) Strips of filter paper 0.5 cm. wide and 1 to 3 cm. long were placed on the upper side of the leaves. Three drops of the active solution containing a total activity of 0.05 μc. were placed on the filter paper. When dry the filter paper was removed. In this way a quantity varying from 0.003 to 0.010 μc. was spotted on to an area of 0.5 to 1.5 sq. cm. in spite of the waxy surface of the leaf.

(ii) By turning leaves over and holding them by a loose paper clip, similar applications were made to the underside of the leaves. When the filter paper was dry, it was removed and the leaf was allowed to return to its normal position.

(iii) The tips of leaves were immersed for 4 hours to a depth of from 1 to 2 cm. in the active solution.

(iv) About 5 cm. of the stalks was painted with the solution.

(v) No application was made to this group.

(vi) In the case of corn, drops of the solution were placed in the small funnel formed by the developing leaves around the stem. The initial activity was of the order of 0.02 μc.

Assay

Various sections of duplicate plants from the splashed and spotted plants were taken after 4 hours, 1, 5, 12, and 20 days from the time of application of the phosphate. These were placed in counting cups and set under the window of an end-on Geiger Mueller tube.

FIGURE 1. Forty-two-day-old bean plant. This plant was exposed to "splash" (shaded portion) from raindrops on the thirtieth day. The numbers represent the counts per minute recorded 12 days later, due to absorbed P^{32}.

FIGURE 2 Forty-two-day-old bean plant. This plant was "spotted" (solid portion) on the upper surface with 0.008 μc. of P^{32} on the thirtieth day. The numbers indicate the activity in counts per minute 12 days later.

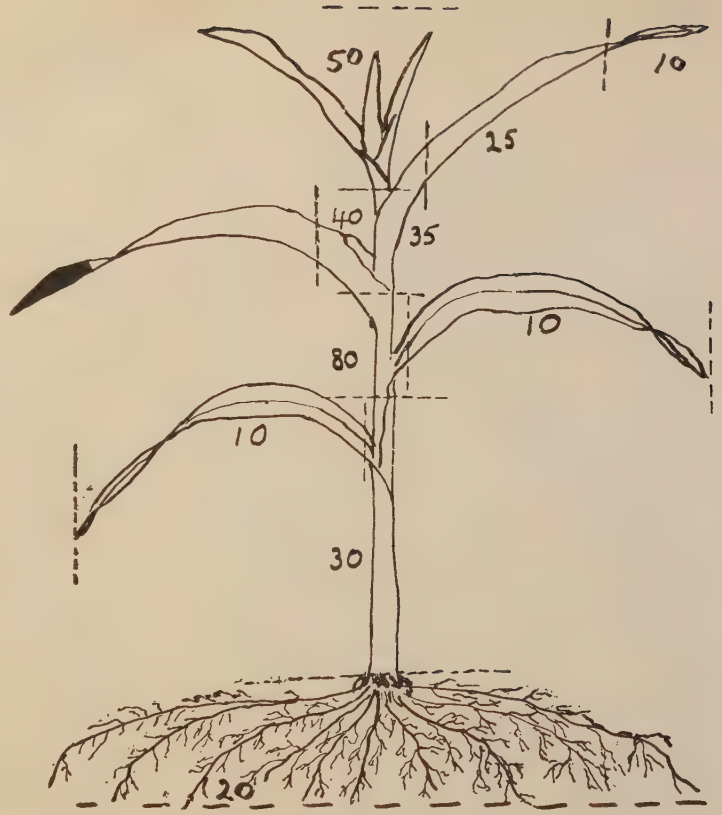

FIGURE 3. Forty-two-day-old corn plant. The leaf tip (solid portion) was dipped in an active solution for 4 hours on the thirtieth day. The numbers represent the counts per minute recorded 12 days later, due to absorbed P^{32}.

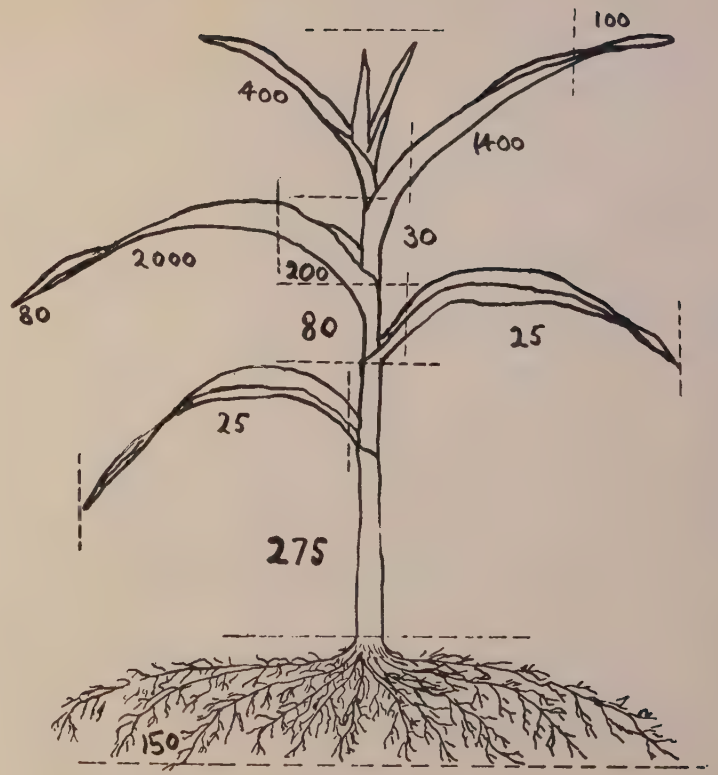

FIGURE 4. Forty-two-day-old corn plant. 0.02 μc. of P^{32} in solution was placed in the small funnel formed by the developing leaves around the stem on the thirtieth day. The numbers are the counts per minute measured 12 days later.

RESULTS

The experiments were qualitative rather than quantitative because of the variable amounts of active material that adhered to the leaves at the outset. In spite of this, certain distinct observations were made from which important inferences may be drawn:

1. The foliage of corn and beans was capable of absorbing phosphorus and translocating it to all parts of the plant. At the end of 20 days 3 per cent to 20 per cent of the initial activity had been translocated from the leaf on which the original application was made. Figures 1-4 are four typical cases illustrating the order of magnitude of the absorption and translocation. The shaded portions in Figures 1-3 indicate the initial location of the active phosphate. The numbers are integrated counts per minute for the indicated sections of the plant.

2. Translocation in appreciable quantities from a leaf to other parts of the plant was a relatively slow process requiring hours and days.

3. The greatest activity appeared in the rapidly growing parts of the plant; and in the case of beans there was considerable concentration in the blossoms and later in the seed. The rate of absorption into and translocation from old leaves was very small.

4. The splashed plants all showed activity throughout, but two plants which had been sprayed two days after the rain with water from a household fly spray exhibited somewhat higher activity.

5. The upper surface of the leaf was more effective in absorbing the phosphorus than the lower side.

6. The plants with the painted stems displayed only a slight absorption and subsequent translocation.

7. In those plants in which the tips of the leaves were dipped and thus kept wet for 4 hours, the activity in all sections of the plant was much higher than in any of the other spotted (on leaf or stem) test plants.

8. Corn plants (Figure 4), however, with the active solution placed in the centre where the folded developing leaves emerge showed the highest activity (10-20 per cent) throughout the plant. Moisture probably played an important role, again, as the solution evaporated very slowly from the confined space. A considerable portion of the phosphorus remained where placed and moved out with the elongating leaves.

DISCUSSION

From the evidence presented above it would seem that in cases where fertilizer is applied to the surface of the soil, a certain portion of the phosphorus content of the plants may come from the fertilizer particles splashed on to the leaves by falling raindrops. These particles may act for some time as a source of phosphorus, with dew playing an important role in making the soluble phosphorus available for the absorption-translocation process. Such a splash effect may serve as a valuable asset for increasing the phosphorus content of grasses in pastures.

It appears also that the phosphorus content of corn and beans may be increased by spraying the foliage with a soluble phosphate solution. The most effective time for spraying would be shortly after a rain, when the

plant would be growing rapidly. Furthermore, the few days of dry weather with dew at night would probably enhance the absorption. Whether spraying with a phosphatic fertilizer can be placed on an economical basis remains to be tested.

SUMMARY

Using a labelled phosphatic fertilizer it has been shown that phosphorus applied to the foliage of beans and corn can be absorbed and translocated throughout the plant. The absorption and translocation is greatest in the rapidly growing parts of the plant.

The phosphorus content of beans and corn in locations where phosphatic fertilizers have been applied to the surface of the soil may be due in part to absorption from fertilizer particles splashed on to the leaves by raindrops.

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PHLOEM NECROSIS OF POTATO TUBERS ASSOCIATED WITH INFESTATION OF VINES BY *PARATRIOZA COCKERELLI* SULC.[1]

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In previous reports (2, 9, 10, and 11), it was stated that tuber phloem necrosis was associated with the feeding of *Paratrioza cockerelli* Sulc. on apparently healthy potato vines in open field culture during July and August in Alberta. Richards and Blood (7), who first described psyllid yellows, did not find this symptom, and since then other investigators, including List (4), have not found that tuber phloem necrosis is associated.

A description of the disorder and some experimental results obtained are presented for their interest and as a matter of record.

HISTORICAL

The first outbreak of ordinary psyllid yellows reported in Canada occurred at Medicine Hat, Alberta, in 1932 (8), when about 100 acres of potatoes at different places in and near the city were severely affected. Earlier the same season, the tomato crop in many commercial greenhouses at Medicine Hat was heavily infested with *P. cockerelli*. Apparently psyllid yellows was not reported again until 1936, when severe local outbreaks occurred on potatoes at Medicine Hat, Calgary, Lethbridge, and in several garden-plots at Edmonton. The malady at Edmonton was definitely traced to tomato seedlings shipped from infested greenhouses at Medicine Hat. In 1937, psyllid yellows of potatoes was reported as slight at Medicine Hat and fairly severe in several gardens at Calgary. It should be emphasized that up to and including 1937 phloem necrosis of the potato tubers on affected plants was not a symptom.

During midsummer of 1938, a very disastrous outbreak of what first appeared to be psyllid yellows developed at several points in southern Alberta, but with the additional symptom of a very severe and general phloem necrosis of the tubers. The disease was severest at and near Medicine Hat, Lethbridge and Calgary (Figures 1, 2, 3, 4). A general and very serious epidemic of ordinary psyllid yellows of potato was reported as having occurred in 1938 in the adjoining State of Montana as well as in Wyoming and Nebraska (U.S.D.A. Plant Disease Reporter 23 : 1 and 4; 18 and 35. 1939), but apparently tuber necrosis was not present. In 1939, the symptoms and severity of the phloem necrosis disease in southern Alberta were the same as in 1938. In 1940, the disease appeared again in severe form at Medicine Hat, Lethbridge, and Calgary, but, with a few exceptions, the outbreaks were local and the total damage relatively slight. No doubt its sudden reduction resulted from the fumigation of the psyllid-infested greenhouses at Medicine Hat, Lethbridge and Calgary by officials of the Alberta Department of Agriculture.

From 1941 to 1943, inclusive, there was no record of this malady anywhere in Alberta, except near the psyllid-infested greenhouse of the

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Dominion Entomological Laboratory, located at the Experimental Station, Lethbridge. During the winter of 1943-1944, the population of *P. cockerelli* in this greenhouse perished from critically low temperatures. Since then the malady under consideration has not been observed in Alberta.

SYMPTOMS

On Mature Plants in the Field during Midsummer, or Later

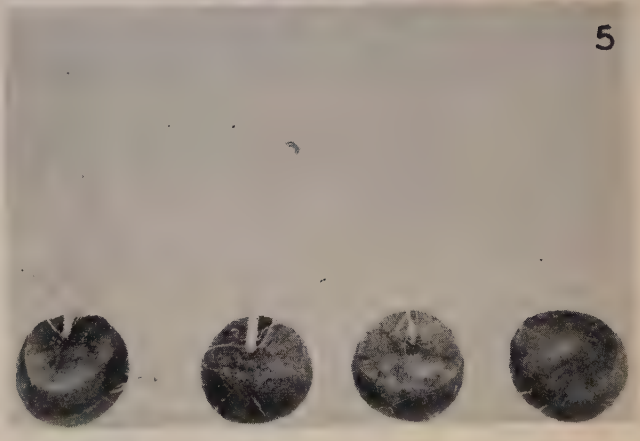
Except for the fairly constant occurrence of severe internal phloem necrosis of the tubers borne on newly affected plants, and a very significant reduction of the tendency of such plants toward a pyramidal type of growth, the general symptoms of the malady now being described closely resemble those given by Richards and Blood (7) for psyllid yellows of potato. Undoubtedly the malady is systemic. The form and physiology of the entire plant are obviously abnormal. The symptoms are first visible on the apical shoots. Under field sunlight intensity during July and August, the terminal shoots of large, healthy plants usually begin to show the symptoms in from 8 to 10 days, depending upon the density of the insect population present on the stalk or stalks of a plant. Such affected plants apparently cease growth and slowly degenerate, but do not die prematurely. In strong field sunlight, the foliage of affected plants that have genetic factors for the expression of colour usually develop various intensities of red or purple, but varieties such as Netted Gem, with apparently no genetic factors for colour, become more or less chlorotic. The leaves are cupped as in leafroll, but they are much thinner and less brittle than leafroll affected leaves. The internodes become short, the nodes enlarge, and the axillary buds swell to form short shoots with rosettes of malformed leaves and, commonly, aerial tubers. Diseased plants in the field are easily recognized by their abnormal appearance (Figure 1, *1 and 2*). In older plants, where tuberization is advanced, stolon and tuber development appear to be normal. If there is a very low insect population on the foliage of certain stalks of a plant, the tubers on them may fail to develop phloem necrosis.

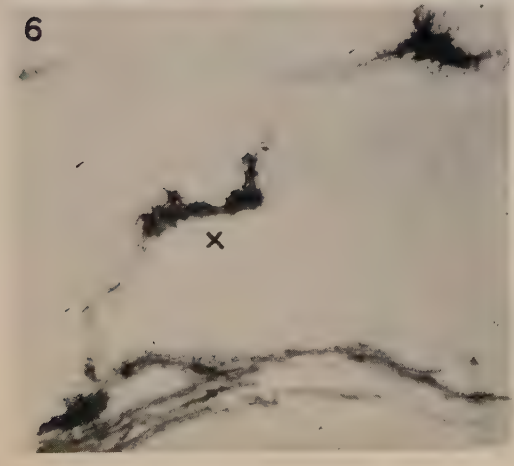
Furthermore, tuber phloem necrosis is usually distributed throughout the tuber and does not tend to be confined to the proximal half, as in leafroll. It should be emphasized that tuber phloem necrosis and the general plant symptoms of this disorder, such as stunting of the plant, shortening of the internodes, swelling of the nodes, cupping of the leaves, and the appearance of pigments, also occur with certain variations in some other potato diseases caused by fungi or viruses.

The various tuber and plant symptoms of the malady on Netted Gem potato plants and tubers are shown in Figure 1.

FIGURE 1. Photographs of various abnormal symptoms of Netted Gem potato vines and tubers when normal plants in the field became naturally infested during July and August with a population of *Paratrioza cockerelli*.

1. Characteristic symptoms in field on potato vines, about 10 days after infestation.
2. Incipient symptoms of axillary growth on potato vine recently affected.
3. Tuber with all eyes dead as a result of severe phloem necrosis.
4. Vigour of tuber sprouts as influenced by severity of phloem necrosis. *Left*, Control (Edmonton). *Right*, Top, moderate; Bottom, severe.
5. Roots from affected vascular area of different tubers having (*left to right*) trace, light, moderate, or severe phloem necrosis.
6. Magnified, discoloured phloem elements and adjacent cells from an affected tuber.
7. "X" in No. 6 more highly magnified.





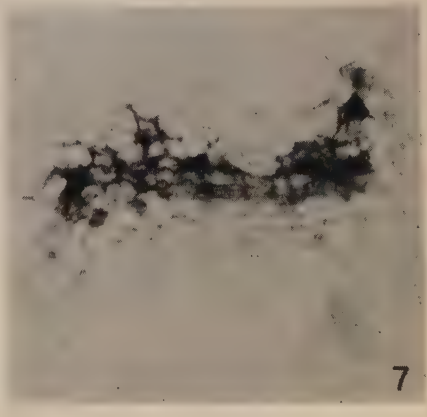


FIGURE 1

FIGURE 2. Early Ohio plant grafted in greenhouse during early August with scions from newly affected Netted Gem plant. It shows modified vine symptoms but severe tuber phloem necrosis.

On Affected Plants under Canvas or Greenhouse Conditions

When healthy plants, grown under canvas in the field or in the greenhouse, are infested with psyllids, they apparently do not produce tubers that have phloem necrosis, and other symptoms associated with psyllid infestation are also much modified in comparison with those of affected plants growing in the field. For example, the extreme and rapid cupping of the leaves, and the appearance of purple and red pigments so common under ordinary sunlight, usually do not occur. Instead, the leaves and leaflets gradually turn yellow and become stunted. The chlorosis begins in the area between the veins. Such affected plants also tend to persist longer than healthy ones. Apparently this description is very similar to that given by Richards and Blood (7) for ordinary psyllid yellows of potatoes under reduced sunlight.

ETIOLOGY

According to observational and experimental evidence obtained in this study, the tuber phloem necrosis and the other plant symptoms mentioned result from the feeding of *P. cockerelli* on healthy potato vines under field culture during July and August. The problem appears to have a number of important aspects. For example, one asks if both nymphs and adult insects transmit the causal agent, and whether it is a virus or merely a toxic substance; also, what relation has light intensity, age of plant, and variety, to symptom expression, and is the causal agent transferable by grafting?

Role of Paratrioza cockerelli

A number of experiments were made at different localities in southern and north-central Alberta during the years 1939, 1940, and 1941, in order to determine if the malady resulted from the feeding of the tomato psyllid on healthy potato vines.

About 50 untreated sets of healthy, certified Netted Gem potatoes, grown in northern Alberta, were planted about the first of June in each of six widely-separated fields in rows or plots, as convenient. Notes were taken periodically during each season until the plots were harvested. Caged controls were not necessary because the plants from the same stock were exposed in north-central Alberta, where the psyllid was not known to be present, as well as in southern Alberta, where it was abundant. Moreover, it seemed necessary to have the plants exposed to full sunlight at each location. Natural field infestation by *P. cockerelli* was depended upon.

The data in Table 1 indicate that the stock planted was healthy, because each year the plants in the plots at Edmonton and Olds, in north-central Alberta, remained normal. No abnormal symptoms were evident on the plants in north-central Alberta, where no psyllids were observed, whereas typical symptoms of the disease herein described developed on the plants in the plots at Calgary, Medicine Hat, Taber and Lethbridge, in the known psyllid-infested area of southern Alberta. Furthermore, these symptoms resulted from an observed population of *P. cockerelli* on the vines. The results from this experiment showed that the affected tubers produced more or less weak sprouts, or none, depending on the intensity

TABLE 1.—PERCENTAGE HEALTHY POTATO PLANTS NATURALLY INFESTED[1] WITH *Paratrioza cockerelli* THAT PRODUCED TUBERS HAVING PHLOEM NECROSIS

Location of plot	1939	1940	1941
Infested areas[2]			
Lethbridge	100	100	100
Taber	100	10	0
Medicine Hat	100	68	0
Calgary	72	12	0
Non-infested areas[3]			
Olds	0	0	0
Edmonton	0	0	0

[1] During July and August, in field sunlight.
[2 and 3] Southern and north-central Alberta, respectively.

of phloem necrosis present in them (Figure 1, *3, 4, and 5*). Often certain tubers on these infested plants failed to develop phloem necrosis but always their sprouts were subnormal in vigour.

Development of Tuber Phloem Necrosis under Canvas in the Field and under Greenhouse Conditions

Richards and Blood (7) reported that under greenhouse light, symptoms of psyllid yellows were produced consistently within about ten days by as few as 30 active nymphs of *P. cockerelli* when applied to healthy potato plants on September 23, 1927, or the following March. These authors also found that, in tests made during late autumn, the characteristic symptoms of psyllid yellows failed to develop on plants infested with as many as 60 to 75 nymphs. As a result of further experiments, they mention that "both the *intensity* and *duration* of sunlight in some way either influence the insect during its feeding or determine the type of symptom expression". This observation may be very significant in helping to explain the marked differences, already mentioned, in plant symptoms and tuber phloem necrosis as between field and greenhouse, or shaded culture.

Recovery of Progeny of Potato Plants Attacked by Paratrioza cockerelli

Richards and Blood (7) found that, except when the plant already had developed very severe symptoms, the affected plants soon became normal again if the feeding nymphs were removed. Similar experiments were not made in the present study. However, tests were carried out in the absence of the tomato psyllid at Edmonton, under field conditions, on the recovery of plants from affected stock grown at Lethbridge. In 1939, and again in 1940, one typical necrotic tuber was selected from each of 50 affected plants of the Netted Gem variety. In the following year, one set was cut from each of these tubers and planted at Edmonton. Notes were taken on the health of each plant unit during the first and second year of test. Some of the tubers originally selected for the experiment had such severe phloem necrosis that they failed to sprout or they produced weak sprouts that did not survive. The records show 64 per cent survival from the affected tubers selected in 1939, and 76 per cent from those selected in 1940. The sprouts that survived produced weak plants at first, but, when once

established, the plants tended to recover and to produce normal tubers. Recovery of the selections during the second year of test was complete. The degrees of temporary or complete loss of vitality, as indicated by sprout vigour, are shown in Figure 1, *2*, *3*, *4 and 5*. It should also be recorded that roots emerged from the vascular ring of affected sets, even though the sprouts remained practically dormant (Figure 1, *5*).

It was concluded from the foregoing experiments that the loss of vigour just mentioned resulted from the infestation of the vines under field conditions during July and August by *P. cockerelli*, and that, in general, the weakened plant vigour was directly proportional to the degree of tuber phloem necrosis that developed as a result of such plant infestation. Apparently this loss of vigour is a result of some obscure substance injected into the plant by the feeding insect and the plant's reaction to it under strong sunlight. At least full recovery in two generations, and no obvious sign of the leafroll virus in the generation following the original attack, strongly indicate the absence of this virus. However, it does not exclude the possibility of one or more latent viruses being present and having caused or contributed to the symptoms mentioned.

Varietal Susceptibility

During 1940 and 1941, many varieties of potatoes in the plots at the Experimental Station, Lethbridge, and elsewhere in the psyllid-infested area, were observed for their ability to develop tuber phloem necrosis and allied chlorotic plant symptoms caused by *P. cockerelli*. The following varieties were definitely susceptible: Netted Gem, Carter's Early Favourite, Early Ohio, Warba, Triumph, Wee McGregor, Green Mountain, Cobbler, Epicure, Early Rose, Table Talk, and Rural Russet. Varieties not observed included: Canus, Katahdin, Menominee, Pontiac, and Sebago.

Transfer of Causal Agent by Grafting Technique

Several attempts were made to produce, experimentally, tuber phloem necrosis and associated vine symptoms by grafting scions from plants affected at Lethbridge into healthy ones grown at Edmonton. At first the scions were obtained from plants having rather severe symptoms, but the results were always negative. It was thought that in the plant already exhibiting severe symptoms, the active principle might not be transferable, or at least ineffective in producing tuber phloem necrosis. Consequently, during early August, one plant of the Netted Gem variety in the Lethbridge plot, which showed incipient symptoms of infection, was carefully transplanted and promptly brought to the Edmonton laboratory. There scions from it were grafted at once on to four apparently healthy test plants of the Early Ohio variety. The test plants, which were in pots, were placed on the greenhouse bench close to the unshaded glass. After about 14 days, all of the tubers on the four grafted plants developed typical phloem necrosis. The vine symptoms were subdued. There was axillary sprouting, internodal swelling, terminal growth, and a trace of anthocyanin colour. The ungrafted control plants remained normal. The experiment was made during early August, when the sunlight was intense. Photographs of one of the grafted plants and a cross-section of one of its necrotic tubers are shown in Figure 2.

Although interesting, these results merely suggest that the effective agent can be transmitted to healthy plants by grafting technique, providing the scions are taken from plants with incipient symptoms. Data from subsequent tuber index tests proved beyond reasonable doubt that the tuber phloem necrosis referred to was not a result of primary infection by the leafroll virus. However, it is still possible that latent viruses were present and, also, there is a remote chance that the tuber phloem necrosis and associated plant symptoms could have been produced by stray nymphs that might have remained on the scions used, although such nymphs were not observed. Unfortunately these tests could not be repeated the following year, because the experimental population of *P. cockerelli* perished from a critically low temperature.

DISCUSSION

According to the evidence submitted, the abnormal phloem necrosis of potato tubers and associated vine symptoms described was associated with an infestation of *P. cockerelli.* Under full sunlight in field culture, both nymphs and adults appeared to be capable of inducing both vine and tuber symptoms. Full recovery of progeny from affected plants to normal health and vigour in the absence of the insect infestation suggests that the symptoms were induced by a very toxic and probably an autocatalytic substance injected by the feeding insect rather than by a virus transmitted by it.

The symptoms of the malady are very different from those produced by the virus which, recently, Oswald (5) found to cause necrosis of potato vines and tubers, or from those produced by the yellow dwarf virus (1, 12). Also, they are different from those listed by Orton and Hill (6), or by Leach and Bishop (3) for the blue-stem disease of potato, or from those caused by any other known virus. Moreover, data from tuber index tests revealed that the leafroll virus was absent.

If the causal agent is not a virus, then, as suggested by Richards and Blood (7) for the psyllid yellows disease of potatoes, it must be a toxic substance secreted by the insect. The question is whether or not the same toxic substance is responsible for ordinary psyllid yellows as for psyllid tuber phloem necrosis and associated vine symptoms. If the causal agents are essentially different in nature and have not the same response to light intensity and perhaps other factors, then it seems that the symptoms for each malady should be described separately. However, this might not be necessary if all the facts were known. Again, it is possible that difference in the toxic agent might be the result of mutation in the insect which affects the capacity of the secreted substance to produce tuber necrosis. If so, the mutant and parent population could co-exist unrecognized except for the mutation mentioned. This hypothesis may seem attractive, but, unfortunately, it could not be verified because the population of insects that caused the trouble was accidentally frozen and lost.

SUMMARY

According to observational and experimental evidence, the intense tuber phloem necrosis and associated vine symptoms here described, developed in about 10 days as a result of nymphs and adults of *Paratrioza cockerelli* feeding on apparently healthy potato vines in open field culture during July and August.

Present evidence indicates that the causal agent is a toxic substance injected into the plant by the insect while feeding, and that it soon becomes systemic. Apparently it is not a virus, because plants from affected tubers are merely weak in the first season and normal in the next tuber generation. It is suggested that the sudden appearance of tuber phloem necrosis in Alberta in 1938 was due to a genetic mutation in the local psyllid population.

Further positive evidence that the causal agent can be transferred to healthy plants by grafting technique is required.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the contributions at the beginning of this study of S. B. Clay, formerly on the research staff of this laboratory; and also the assistance with the photographs of E. W. Burton, formerly assistant technician at this laboratory.

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A BORON DEFICIENCY IN PEAR GROWING IN SOIL HAVING AN ADEQUATE BORON CONTENT[1]

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A die-back condition in apple, described by McLarty (4) in 1928, is "characterized by the apparent inability of the tree to put out normally its buds on last year's terminal growth, or by its tendency to put out a sickly cluster of leaves that soon shrivel and die, the bud and cambium being at the same time in apparently healthy condition". This disorder in apple, and also a similar condition on most other fruit trees growing in the Okanagan Valley in British Columbia, has since been shown to be caused by a deficiency of boron (5, 6). In this paper a similar condition on pear, which developed in an area where soil applications of boric acid had been made in accordance with general recommendations, is described and the results of analyses for boron content are presented.

During the first half of May, 1951, the blossoms on many pear trees in three orchards growing on the Trout Creek Point area shrivelled and died (Figure 1). Most leaf buds failed to develop even though the bark and cambium were in an apparently healthy condition. During June, however, a high percentage of the leaf buds on the spurs of which the blossoms had died began to grow (Figures 2 and 3) and, as the summer progressed, the foliage developed normally and considerable twig growth was made. The application of a foliage spray, 1 pound of boric acid in 100 gallons of water, speeded the recovery but, at the end of the growing season, no difference could be detected between sprayed and unsprayed trees. Samples of shrivelled and healthy blossoms and leaves and twigs of affected and non-affected trees were collected for analysis. Samples of soil, which was powdery dry, were also obtained from the affected area. The tissue samples were analysed for their total boron content and the soil samples for water soluble boron by the turmeric method (7). The results of these analyses are presented in Tables 1 and 2. They indicate a boron content of the affected tissues that is associated with deficiency symptoms and a boron content of the soil that is adequate for normal tree development (10).

Table 1.—The boron content of pear tissues
(p.p.m. on a dry weight basis)

Tissue	Condition	Boron content
Blossoms	Shrivelled	2.5
	Healthy	17.5
Leaves	Affected tree	1.0
	Affected tree	0.5
	Healthy tree	10.3
Twigs	Affected tree	1.5
	Healthy tree	4.0

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FIGURE 1. A branch of a pear tree affected with severe die-back and on which the blossoms have shrivelled.

FIGURE 2. An affected branch on which some of the leaf buds have developed and the shrivelled blossoms are still attached.

FIGURE 3. A severely affected tree on which some of the leaf buds have started to grow while others have failed to develop. Note the healthy foliage on the trees on either side of the affected one.

TABLE 2.—THE BORON CONTENT OF SOILS

(p.p.m. on a dry weight basis)

Description	Boron content
Top soil (0- 6") location A	2.30
Sub soil (6-12") location A	1.02
Top soil location B	2.84
Sub soil location B	1.12

Several authors (1, 2, 3) have found that low soil moisture interferes with the absorption of boron by a plant and that symptoms of deficiency therefore are more prevalent in years of low precipitation. The small amount of moisture in the soil in the area where the reported deficiency occurred appears to offer an explanation for its occurrence. The trees which were affected are not irrigated but depend upon natural precipitation and seepage for their moisture supply. The latter comes in part from a creek and in part from excess water used in irrigating neighbouring orchards which are on a higher level. The flood period of the creek runs from the middle of May until the end of June. Irrigation starts about the middle of May and continues until the end of August. Thus, during the summer months, the affected area is well supplied with water. Critical moisture conditions can develop only during the fall or the early spring months (8, 9). In former years the orchards from which the seepage arises were irrigated by the furrow system and the particular nature of the soil permitted the building up of large amounts of excess water. This continued to pass through the soil into the affected area during the fall months with the result that the trees were well supplied during that period. Two years ago, however, sprinklers were installed in the higher orchards, about 30 per cent less water is now used (9), and as a consequence, the flow of seepage water stops much earlier. There was also one additional factor that would tend to aggravate the condition. Normally, orchards depend on melting snows and early spring rains to supply moisture until the irrigation starts in the middle of May. In 1951 the natural precipitation in April was only 0.24 inches compared with a 25-year average of 0.80 inches. It would appear, therefore, that the reduction of seepage water during the fall, coupled with an exceptionally dry April, was responsible for the development of the deficiency in these trees this year.

SUMMARY

1. A disorder in pear trees, similar to that caused by a boron deficiency, is briefly described.

2. Chemical analysis of affected tissues indicated a boron content that is normally associated with deficiency symptoms.

3. Chemical analysis of the soil in which the trees were growing indicated a boron content that is adequate for tree development.

4. A lowering of the soil moisture content in the fall and early spring is considered to be responsible for the occurrence of the deficiency.

ACKNOWLEDGMENTS

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THE PHENOMENAL DECLINE OF BROWNING ROOT ROT (*PYTHIUM* SPP.) ON THE CANADIAN PRAIRIES[1]

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One of the most striking features in recent years in the over-all plant disease situation on the Canadian Prairies, but more particularly in Saskatchewan, has been the phenomenal decline, and virtual absence in certain years, of browning root rot. Any plant disease which was as widespread as this one and the cause of so much concern among farmers, and which became in a relatively short time of negligible importance, presents an interesting case for plant pathologists. The factors leading to its decline should be analysed. This analysis would mainly serve a twofold purpose: *first*, to continue in operation those beneficial practices which would prevent the recurrence of the disease, and *second*, to provide evidence which might be of value in the control of other similar plant diseases. In this paper, relevant facts on the case are presented and discussed.

Shortly after investigations on root diseases of cereals on the prairies were undertaken in the 1920's, browning root rot, caused by species of *Pythium*, of which *P. arrhenomanes* and *P. tardicrescens* are the principal pathogens, was found to be one of the three major root diseases attacking cereal crops. The other two were common root rot caused by *Helminthosporium sativum* and *Fusarium* spp., and take-all caused by *Ophiobolus graminis*. Browning root rot was most damaging to the summerfallow wheat crops. It was more generally prevalent in Saskatchewan than in Manitoba and Alberta and was consequently studied more intensively here. In most years the losses from this disease were estimated to be as great as those caused by common root rot, and in years of severe browning root-rot outbreaks, such as those which occurred more particularly in 1928, 1933 and 1939, the losses from this disease exceeded those from common root rot. Conservative estimates placed average annual losses from browning root rot in these three years at about $10,000,000 in Saskatchewan alone (14).

DECLINE OF BROWNING ROOT ROT

According to the Canadian Plant Disease Survey (3) and records at the University of Saskatchewan, the disease fluctuated in severity, without any definite sign of lessening, throughout the 1930's. In 1939, the last widespread and severe outbreak was recorded. For the next three years, recorded cases, and particularly severe ones, were well below average. In 1943 and 1944 there were localized outbreaks of the disease on the Regina plains, and in the latter year also several hundred acres were affected west of Edmonton. From 1945 to 1948 only an occasional lightly infested field was found on surveys in Saskatchewan, while no reports were recorded from Manitoba or Alberta. In 1949 no report of the disease appears in the Plant Disease Survey. The general decline and virtual disappearance of browning root rot was now apparent to farmers and plant pathologists

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[2] Professor of Plant Pathology.

alike. A careful search for the disease in localities where it had been once serious was made in 1950 and 1951 during June when the symptoms of the disease are most characteristic; evidence bearing on the question was also collected.

Fields showing the slightest suspicion of browning root rot symptoms from the roadway were examined for root lesions. Of several dozen such fields only six showed light lesions. Information on three of these six revealed that two had never received phosphatic fertilizer supplements and the third had received only two dressings. This last field had suffered from wind erosion some years previously. Combine harvesting had been employed on these farms for four or five years so that total crop residues had been returned to these fields only two or three times depending on the rotation used.

SITUATION BEFORE THE DECLINE

Browning root rot was primarily a disease of the wheat crop following fallow and appeared to be one which increased under the crop-culture methods prevailing on the prairies. It was rarely found on the second wheat crop after fallow. All the cereals and cultivated grasses are attacked, but as wheat is the crop chiefly grown on fallowed land, this crop suffered most. Greatest losses were frequently sustained on crops following bare, dust mulch summerfallows which had been thoroughly and frequently worked, and where, previously, good yields had been obtained. In diseased fields, growth was usually best at the edges and in burned straw-pile areas. The ploughing under of heavy weed growth at the beginning of the fallow was definitely beneficial, and was regularly practised by certain farmers. The disease was most common on land—regardless of soil type—which had been under cultivation for many years. It first showed up as brown patches in the fields when the plants were about five to six inches high. Both primary and crown roots showed signs of decay, with the brown lesions at the tips of the crown roots presenting a characteristic underground symptom. Reduced tillering, slight stunting and delayed maturity followed. Competition against weeds was reduced. In moist years partial or apparent recovery would be observed in some fields. Yields were reduced three to ten bushels per acre. The disease was found in all parts of the wheat-growing area of Saskatchewan, but was never conspicuous enough to attract attention in the drier southwest where water is primarily the limiting factor in crop production. Reports of severe outbreaks were more frequent from Alberta than from Manitoba, but in neither of these provinces did the disease cause as much concern as in Saskatchewan. In general, soils in the parkland began to show signs of producing diseased crops sooner after breaking than soils in the prairies.

MAIN RESULTS OF INVESTIGATIONS

The findings in this section are taken from a series of papers on browning root rot by Vanterpool and collaborators (10 to 15), who began their investigations at the University of Saskatchewan in 1928. More detailed information on the disease will be found in reference 12 which is a summary of studies on the disease up to 1939. It was found that the disease was caused primarily by one or more species of *Pythium* which are indigenous

on native grasses. Soil from diseased areas was consistently lower in available phosphorus than soil from normal areas in the same field. No consistent differences in the total phosphorus or in the phosphate-fixing powers of the two respective soil areas were detected. There was a tendency for nitrate nitrogen to be higher in diseased areas. Phosphatic fertilizer amendments in which 0-43-0, 11-48-0 or 16-20-0 was added to soil from diseased areas gave practical control of the disease, increasing the yield above that of normal areas in the same field though some root lesions might still be evident. Applications of nitrate gave slight yield increases or, usually, none at all. Phosphorus was primarily deficient, for once this deficiency was rectified additional dressings of nitrate gave further increases in yield. That the disease was not a straight phosphorus deficiency trouble was shown by the fact that phosphorus was also low in soil from the stubble crop where the disease was rarely observed. Farmyard manure added to browning root-rot soil gave results equally as good as those produced by phosphatic fertilizers. Additions of organic matter in the form of ground cereal straw, sweet clover hay and weed hay to infested soil lessened the disease appreciably. All the commercial varieties of wheat were susceptible to the disease, but Thatcher, in both the greenhouse and the field, showed slightly more resistance than Marquis. In pot experiments, Thatcher showed an average of 12 per cent fewer lesions than Marquis. Slight growth improvements were also obtained by packing infested soil, and moderate improvements by adding cereal straw ashes. The absence of the disease in burned straw-pile areas in diseased fields was attributed to the high available phosphorus present in such areas and not to excessively high nitrate which was found to be about the same as in normal areas in the same field. Crops on wind-eroded fields in which much surface soil had been lost, were more susceptible to the disease. The remaining soil and sub-soil in such fields were lower in available phosphorus and organic matter and of poorer structure than in uneroded fields. These were all factors which rendered the seedlings more liable to the disease. It may be pointed out that the loss of organic matter which amounts to 20 per cent in prairie soils within a few years after breaking when crop residues are not returned to the land (5, 8, 4), has resulted in the susceptibility of the soils to erosion (5). Erdman (5) has shown that wind erosion has caused about 15 per cent loss in organic matter in some medium and fine textured soils in Alberta. In the coarse textured soils the loss amounted to one-third to one-half the original organic matter. These findings probably hold for Saskatchewan where conditions are similar. In summarizing the results in a paper in 1940 on the effects of various soil amendments on the incidence of the disease, Vanterpool (11) states that: "The results as a whole suggest that two of the most practical means of meeting the browning root-rot situation are, firstly, to apply supplemental nutrients in the form of artificial fertilizers, and secondly to add organic residues or farm manure regularly to fields subject to the disease." The phosphorus and manure considerably increased the number and length of the roots, and by producing a more vigorous seedling enabled it to ward off the attacks of the parasitic fungi. Neither amendment appeared to increase resistance as such, at least not appreciably.

PROBABLE CAUSES OF THE DECLINE

The major changes in cereal grain-growing in Western Canada during the last 10 to 20 years will now be considered in relation to the problem and the recommendations previously presented.

The use of high-analysis phosphatic fertilizers as an amendment to cereal crops on the prairies had its beginnings in the early 1930's. By the 1932-33 crop-year approximately 700 tons of these fertilizers were used; this doubled in the next crop-year and trebled in the following year. Between 1935-36 and 1943-44, however, the tonnage used varied between 2,000 and 3,000 with a yearly average of about 2,650 tons. Then began a quick rise which has continued to the present. In each of the crop-years 1944-45 and 1945-46, between 9,000 and 10,000 tons were used, and by 1949-50 the figure had reached 30,500 tons. The sales for the last crop year 1950-51 are approximately the same. Had it not been for the depression and the successive drought years of the 1930's, and the fertilizer quota and scarcity of machinery or attachments for applying fertilizer during the war years, this figure of 30,000 tons would doubtless have been reached much earlier. It is significant that the highest sales of phosphatic fertilizers are in those districts where browning root rot was most severe. It is, therefore, not so surprising that one now seldom finds a case of the disease in such localities as the 1950 and 1951 surveys showed. Farmers in general are inclined to attach most importance to phosphorus as the cause of the disappearance of browning root rot from their fields. Many still associate the trouble with the bare fallow and fine soil mulch formerly in vogue.

Farmyard manure as a soil amendment in cereal growing on the prairies, even on farms with livestock, has never gained favour and its use in the over-all picture may be considered insignificant. Hence it has not affected the browning root-rot situation, except possibly on a very few farms in parkland areas where some mixed farming is practised and the rainfall is higher.

Straw disposal and utilization on the contrary deserve close scrutiny. When browning root rot was a menace, most of the harvesting of grain was done by the binder and thresher. Under this system, the straw was cut relatively short to permit secure tying of the sheaves, and on threshing was deposited in large piles, only a small part of which was used for feeding and bedding livestock, while the remainder was ultimately burned. The only portion of the field which benefited from this practice was the small area under the straw-pile and this received only the mineral content of the burned straw. There was thus a gradual depletion in the organic matter content of the remainder of the field. This depletion was hastened by the general practice of summerfallowing every third and occasionally every other year in some localities, during which conditions favour the breakdown of organic matter by soil micro-organisms. Newton *et al.* (8) have shown that the average losses of organic carbon from the surface six inches of brown, dark brown and black soils in Alberta amounted to about 20 per cent of the original content. As shown by Erdman (5) much of this loss may be attributable to wind erosion. According to Doughty (4) and Erdman (5) this 20 per cent loss of organic matter takes place within a few

FIGURE 1. A typical trash or stubble mulch fallow in June of the fallow year. Summerfallow wheat crops on this field were attacked by browning root rot in the early 1930's when bare fallow was practised. Following the application of phosphatic fertilizer on the summerfallow crops and the adoption of trash fallowing, the disease has disappeared. (Photographed in June, 1951).

years after breaking, so that most soils are relatively resistant to erosion for a few years after being brought under cultivation. The rate of loss is much slower in soils that have been cultivated for 15 to 20 years.

The introduction of the combine method of harvesting led to a change in the disposal of straw. According to census figures there were 6,019 combines in Saskatchewan in 1931; 6,420 in 1936; 11,202 in 1941 and 22,499 in 1946. It is estimated on the trends during the last four years in which figures are available that there are over 45,000 combines in Saskatchewan at the present time. The majority of these are on the prairies, but the increase in numbers in parkland areas has been striking in recent years. Two methods of combine-harvesting are in general vogue. In straight combining, the fine straw and chaff are usually spread evenly over the field behind the combine; in the windrowed method, the cut grain is laid in swaths and after a few days is picked up and combined, the fine straw and chaff being distributed behind the combine in more or less wide rows with bare spaces between. Spreader attachments are not always used. In such case the fine straw is confined to rows. Under straight combining, the stubble is usually cut high, from 12 to 24 inches; under windrowing about 8 inches high. Thus under combining all the straw and chaff may be returned to the land if so desired, and the organic content of the soil reasonably well maintained since only the grain is removed (4). The greater the yield, the greater the amount of phosphorus sold in the grain and hence the quicker the depletion of soil phosphorus from this source.

Van Vliet (16) has estimated that under Saskatchewan conditions the amount of recoverable straw for industrial processing would be about $\frac{1}{2}$ ton per acre for binder-thresher harvesting for average prairie areas, and $\frac{3}{4}$ ton per acre for average parkland areas. These estimates are based on computations in the United States (1) and in southern Alberta (9), allowance being made for local conditions. Thus it would appear that under the binder-thresher harvesting these amounts of straw in prairie and in parkland areas would be lost to the land by straw-piling and subsequent burning of the pile, whereas under combine harvesting all of it can be easily spread over the whole field and ultimately turned under if desired. Data compiled by Doughty (4) show that in the brown soil zone the average annual addition of the crop straw would be equal to the average annual loss of organic matter. In the dark brown and black soil zones where straw yields are usually higher, it is most probable that the annual return of all crop residues would more than compensate for the average annual loss in organic matter.

The practice of trash fallowing or surface cultivation in which the stubble straw is kept in the surface layers and a cloddy surface maintained, came into use in the drought years to prevent soil drifting. It has largely replaced the soil mulch fallow in prairie and parkland (Figure 1).

In localities of high straw yield and under combine harvesting it is sometimes difficult to "work down" the straw properly and prepare a uniform seed bed. In such instances stubble burning is sometimes practised and, though not favoured, slightly better growth in the following crop is usually obtained in the burned than in the unburned areas. This is due to the quick return of minerals, principally phosphorus, in the ash. More lasting benefits would result from turning under the straw.

The use of grasses in the rotation has not had any effect on the over-all decrease in browning root rot as there has been insufficient increase in grass acreage. The same holds for legumes. If any changes have resulted they would be to the good.

Sub-soil packing lessens the disease. There is, however, no evidence available to show that packing has increased, or that the modern machinery ordinarily used in preparing the land produces a firmer seed-bed than that used 15 or more years ago. It could well be that such is the case.

It has already been pointed out that the wheat variety Thatcher is slightly more resistant than Marquis to browning root rot. Marquis was the dominant variety for many years before the widespread introduction of stem rust resistant varieties. In 1936, the year in which Thatcher was introduced, Marquis occupied 72.6 per cent of the acreage in Saskatchewan, but in 1939 it was surpassed in acreage by Thatcher. By 1950, Thatcher occupied 69.2 per cent of the acreage and Marquis 6.2 per cent. In the same year, the percentages of the total wheat acreage in the three prairie provinces were Thatcher 59.7 per cent and Marquis 6.2 per cent. If this change in variety has had any effect on the incidence of the disease, it would doubtless be for the better.

DISCUSSION

The foregoing facts indicate that there are two factors of paramount importance which are responsible for the decline of browning root rot, namely the increase in the use of phosphatic fertilizers on the fallow crop, and the return to the land of most of the crop residue by the combine method of harvesting. Next in importance is the replacement of the bare fallow with its fine soil mulch by the more or less lumpy trash fallow. Most farmers give major credit to phosphatic amendments probably because of the striking, quick response in the fertilized crop. The effects of the first one or two straw additions may be hardly noticeable on the disease, but after a few years the cumulative effects of annual additions are clearly recognized as beneficial. The lumpy trash fallow has held in check the loss of soil phosphorus from wind erosion and produces a soil condition less favourable to disease development than existed under the loose soil mulch fallow.

The phosphatic fertilizer is helpful in three ways: (*a*) by increasing the number and rate of growth of the cereal roots it enhances the competitive power of the seedlings against the parasite, and by improving the phosphate-nitrogen balance possibly produces more resistant cellulose cell walls; (*b*) by increasing the yield of straw all the concomitant benefits of returning crop residues to the land are increased, and (*c*) it counter-balances the drain on the soil phosphorus which is lost in the grain. The beneficial effects from the fertilizer on the disease in the black and in the dark brown soil zones appear to be about the same. It may be noted in this connection that Mitchell (7) found that there was no distinct difference in response of summerfallow wheat crops to 11-48-0 or 0-43-0 between the dark brown and black soils.

Before discussing the effects of organic matter amendments on browning root rot, certain characteristics of the species of *Pythium* causing the disease should be considered. Garrett (6) in his excellent review on

ecological groups of soil fungi has followed Burges (2) in the use of the term "sugar fungi" to denote those soil fungi that are unable to decompose either cellulose or lignin. The sugar fungi are capable of utilizing readily available sugars, simple amino acids, pentosans and possibly hemicelluloses (6). Garrett refers to them as saprophytic sugar fungi which are typically the first colonizers of injured, moribund or dead plant tissues. They are characterized by a high mycelial growth rate, a capacity for rapid germination of spores, and are likely to "flare up" whenever a suitable substrate becomes available. Garrett (6) cites the species of *Pythium* causing damping-off of seedlings and restricted root rots of older plants as a saprophytic sugar fungus of the soil inhabiting class. For the purposes of this discussion, the several species of *Pythium* causing browning root rot may be considered as sugar fungi though the term facultatively parasitic sugar fungi possibly fits the facts better than saprophytic sugar fungi. These species of *Pythium* though doubtless of the soil inhabiting class possess one or two of the outstanding characteristics of the root inhabiting class.

The question to be considered is: Why should these fungi attack the seedlings of the fallow wheat crop on relatively old land on the Canadian prairies? As already pointed out, the cropping system formerly in vogue has reduced the soil organic matter by about 20 per cent of the original content. This has increased susceptibility to wind erosion which in turn has reduced the phosphorus in the surface soil. The sale of each 30-bushel wheat crop represents a further loss of almost 15 pounds of P_2O_5 per acre (17). The condition in the fallow crop could be postulated as follows: Under the dust mulch, bare fallow system of summerfallowing as formerly practised, all of the easily respirable simple carbohydrate material in the soil would be used up by microbial respiration so that by June of the following crop year none would be available for the *Pythium* species which are soil inhabiting sugar fungi. These species of *Pythium* are also incapable of synthesizing biotin, thiamin and other essential growth factors. Through biological action, some of the inorganic soil phosphorus would have been converted into the organic form and thus would not be immediately available to the seedlings. The onset of the early June rains and warm weather would initiate germination of the *Pythium* oospores. The chief source of simple sugars and growth factors would then presumably be the root hairs and unthickened root tips of the wheat seedlings which might have their resistance lowered by the deficiency of available phosphorus as already pointed out. These facts would account for the "flare up" of the *Pythium* which is a common characteristic of this type of fungi as explained by Garrett (6). After a short active mycelial phase when sugars and growth substances are abundant and seedling roots are tender, the fungus parasite reverts to its sexual oospore stage within diseased tissues owing to a decrease in food supply, an increased resistance of the cell walls of the root to penetration, and possibly the onset of warmer and drier conditions. The oospores remain dormant in the soil until conditions favouring their germination arise. This will initiate the "flare up" stage.

Consideration will now be given to the changes brought about by straw disposal under the combine method of harvesting. The disease was frequently worst on well-worked, pulverized summerfallow wheat crops. This type of fallow has been replaced largely by the cloddy surface, trash

fallow type in which crop residues are only partially buried. The benefits derived from the incorporated straw are distributed over the whole field. These include the maintenance or improvement in soil texture and water-holding capacity, the reduction of erosion losses of surface soil, the possible retarding action on inorganic phosphorus fixation, and the return of mineral constituents. Thus about 1.6 tons of straw from a 30-bushel wheat crop will return 5.75 pounds P_2O_5 per acre (17). Under the former method of straw piling, the benefits derived from returned minerals would be confined to one small area. It is thus probable that the crop-culture changes which have come about have influenced the growing conditions for the host plant, especially in the production of a more vigorous root system; also, there are possibly still present in the soil at the beginning of the fallow-crop year some simple carbohydrate straw constituents which are readily utilized by the *Pythium* species. Under former conditions, it is postulated, these simple sugars were lacking in the soil in June following fallow, and the supply in the slightly moribund wheat roots fell prey to the parasite. Now, however, the roots are more vigorous and probably more resistant to fungus attack. It is not considered likely that there has been much decrease, if any, in inoculum potential of the fungus parasite in the soil. The oospores are capable of retaining their vitality for at least ten years in dried soil (13). Furthermore, prairie soils kept free of plant growth for periods up to 18 years, according to available records, were found to harbour the *Pythium* species concerned. Repeated contamination of such soils with oospores during dust storms may have occurred (13). It is probable that the improved conditions brought about by the incorporated straw have produced a microbiological balance which curtails a vigorous "flare up" of the parasite at least at the particular time when the wheat plants are in the seedling stage. Also, phosphatic amendments have more influence on the wheat seedlings than on the fungus parasites, whereas the organic residues have had a greater influence on the inoculum potential of the parasites.

The minor factors suggested as contributing to the decline of the root rot, such as the replacement of the variety Marquis by the slightly more resistant variety Thatcher, the slight, but quick, improvement from cereal straw ash where burning of combine straw is attempted, and various packing operations, though possibly not contributing economic benefits individually in the aggregate may produce substantial improvements. The same holds for introducing into the rotation non-cereal crops which are not susceptible to the *Pythium* species concerned. Alfalfa, sweet clover and flax have been of some value in this regard. Seed treatment was not found to have direct fungicidal or protective action against these fungi, but by helping to control other root diseases and thus produce more vigorous seedlings, may have contributed slight indirect benefits. The use of seed-treating chemicals has increased appreciably in the period under review.

The pertinent question is: Will browning root rot return to the wheat fields of the Canadian Prairies in severe form? The localized outbreaks in 1943 and 1944 on the Regina plains, where more than once epidemics had occurred previously, offer a suggestion. In these war years phosphatic fertilizer was on a quota basis and even if the available supply had been larger, it could not have been applied, as fertilizer attachments for the seed drills were unprocurable. During the war years the disease was also

noticed on isolated farms where it had previously been overcome by the use of phosphatic fertilizer but where, for various reasons, the farmers had stopped using fertilizer. It seems, therefore, that if there is a reduction in the use of phosphatic fertilizer in old districts or its use is not soon introduced in some of the newer settlements where combines are not yet in general use, occasional outbreaks of the disease may be expected. It seems probable, however, that these outbreaks will not be as severe as formerly because of the beneficial effects resulting from the crop practices, referred to above, which have been introduced in cereal-growing on the Canadian Prairies with the advent of the combine and the adoption of cloddy, trash summerfallows. It is hoped that the use of phosphatic fertilizer to replace the phosphorus lost in the grain and by erosion, and the practice of incorporating into the soil all the crop straw not used by farm animals heralds the end of the period of exploitive cropping of prairie soils.

SUMMARY

Browning root rot of cereals was formerly a serious disease of the summerfallow crops on the Canadian Prairies but was rarely found on the second crop after fallow. It has gradually decreased in the last ten years and is now only occasionally encountered. Early investigations showed that it was caused primarily by *Pythium arrhenomanes* and related species and that there was a deficiency of available soil phosphorus in diseased areas. Phosphatic fertilizer applications gave economical control. Farmyard manure and straw amendments were highly beneficial, while burnt straw ashes and packing the soil gave slight improvement. All the common wheat varieties were attacked but Thatcher showed most resistance. Inasmuch as the parasites were soil-inhabiting fungi, it was contended that control measures should be based on all operations which have as their objectives an increase in seedling vigour and an inhibition of the active phase of the parasite. The changes in prairie agriculture in recent years which may have operated in reducing the disease to minor importance are presented and discussed.

The use of phosphatic fertilizers in cereal cropping began in the early 1930's and now averages 30,000 tons annually. It may be significant that the greatest fertilizer sales are in districts formerly most liable to browning root rot. The binder and thresher have largely been replaced by the combine of which there are at present about 45,000 in Saskatchewan. Thus most of the crop residues are now returned to the land by the combine method of harvesting whereas formerly they would have been straw-piled and burned. The adoption of the cloddy trash or stubble mulch summerfallow as a soil erosion prevention practice has replaced the bare fallow with its fine soil mulch and has resulted in the arrestment of loss of soil phosphorus through soil drifting. Thatcher wheat has virtually replaced the more susceptible Marquis.

It is contended that the phosphatic amendments, by removing the soil deficiency and compensating the phosphorus lost in the grain, benefit the growth of the seedlings primarily. The incorporated crop residues and the trash fallow though improving soil texture, reducing erosion, and returning some mineral constituents, are considered to act mainly through complex

microbiological activities which prevent a flare up of the parasite at the time the host plants are in the seedling stage. Outbreaks of browning root rot may occur again, but it is unlikely that they will be as severe as formerly because of beneficial effects resulting from the recent changes in cropping practices.

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ERRATUM

In the paper by J. Mitchell, J. E. Dehm and H. G. Dion, entitled "The effects of elemental sulphur on the availability of phosphate fertilizers", published in the June, 1952 (Vol. 32, No. 6) issue of "Scientific Agriculture", several lines of figures in Table 2, appearing on page 313, were transposed. The lower half of the table, concerning trials at Watson, is printed, with the corrections made, below. The errors occurred in the second line of figures under "Mono-calcium phosphate", and in the second and third lines under "Dicalcium phosphate-nitrate".

Watson						
Mono-ammonium phosphate	0	256	95	79	269	24.0
	1	252	96	78	261	23.9
	5	260	100	78	277	23.9
Mono-calcium phosphate	0	261	98	66	209	20.2
	1	267	102	70	314	21.3
	5	242	91	65	277	19.9
Dicalcium phosphate-nitrate	0	224	81	16	308	5.0
	1	200	73	16	276	4.7
	5	208	75	15	278	4.7
No Fertilizer	0	212	76	—	287	—
L.S.D. (5% level)		30	11	14	N.S.	4.4